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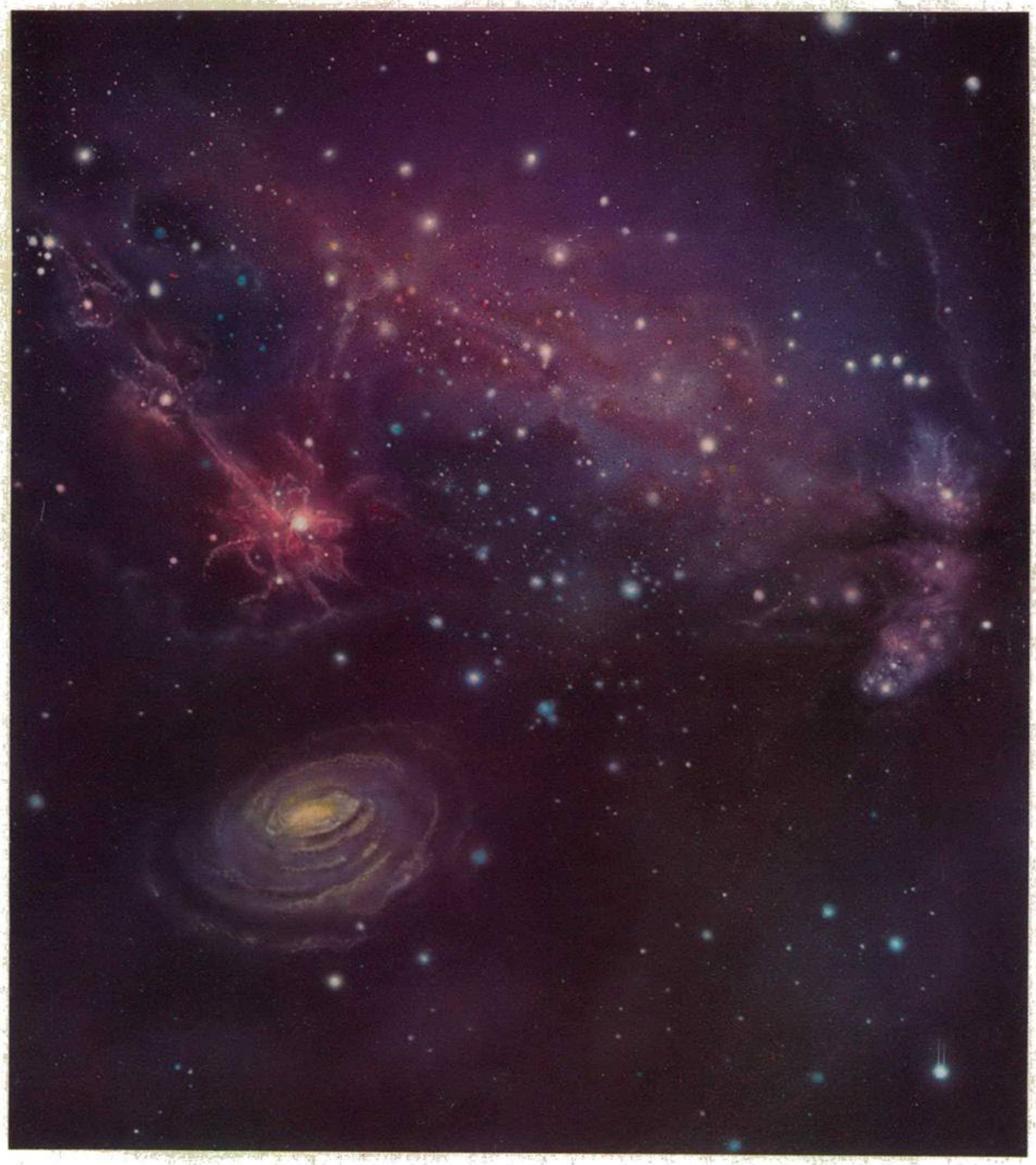

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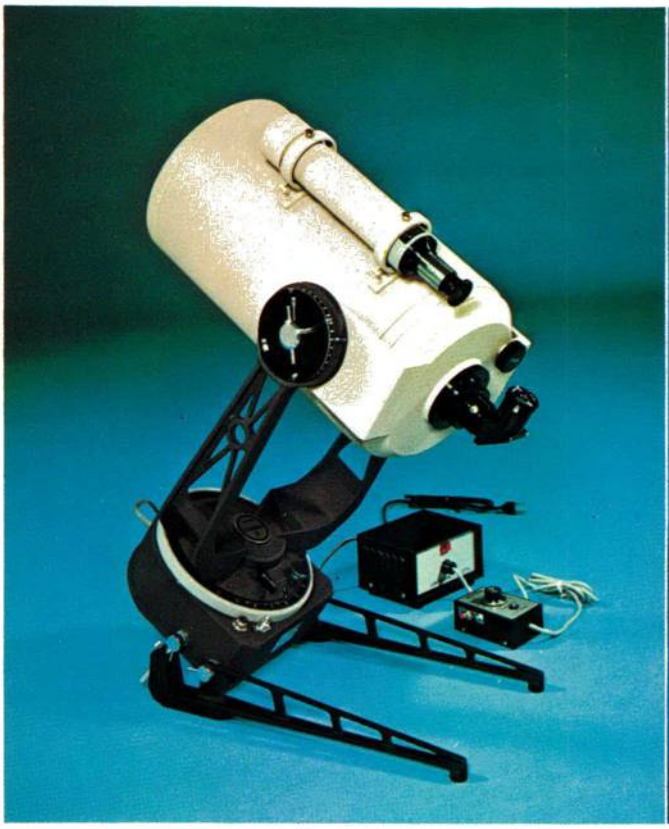

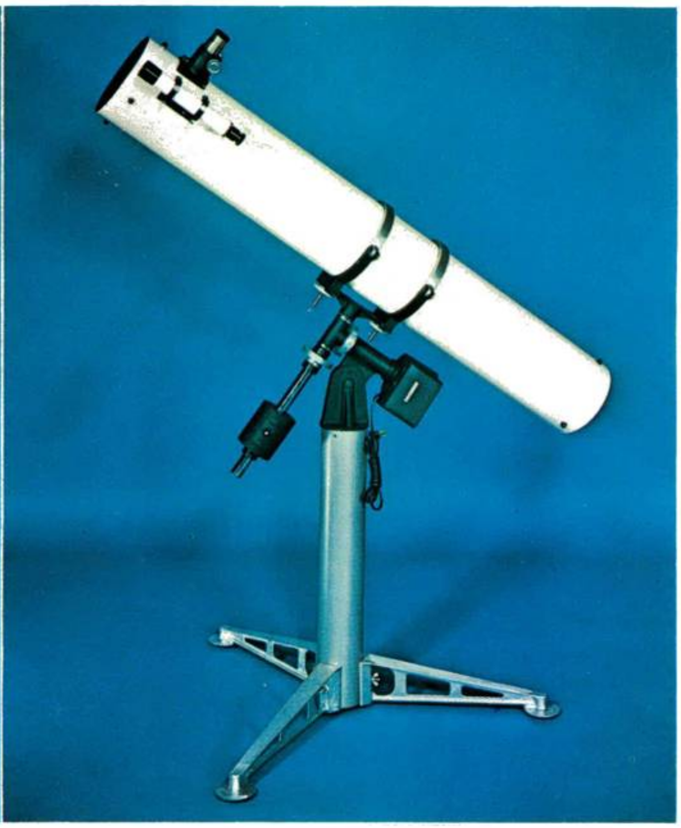

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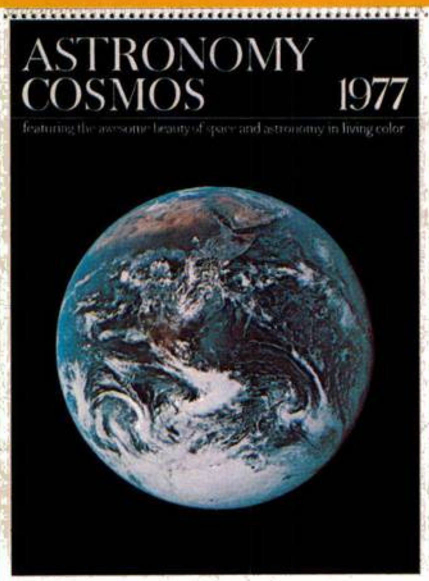
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December 1976 Vol. 4, No. 12

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COVER

If we took a trip to the Large Magellanic Cloud, and then turned and looked back, what would we see? December's cover shows us — from a place just the other side of the LMC — our own spiral galaxy and, somewhat to its side, the Small Magellanic Cloud. This month, ASTRONOMY takes a look at the Magellanic Clouds, and then contacts other planets with radar astronomy. You'll also see the future of our sun and most other stars, as we explore red giant stars. And, there are the down-to-Earth observational challenges of the Messier catalog and techniques for making your own photographs. Artwork by Mark Paternostro.

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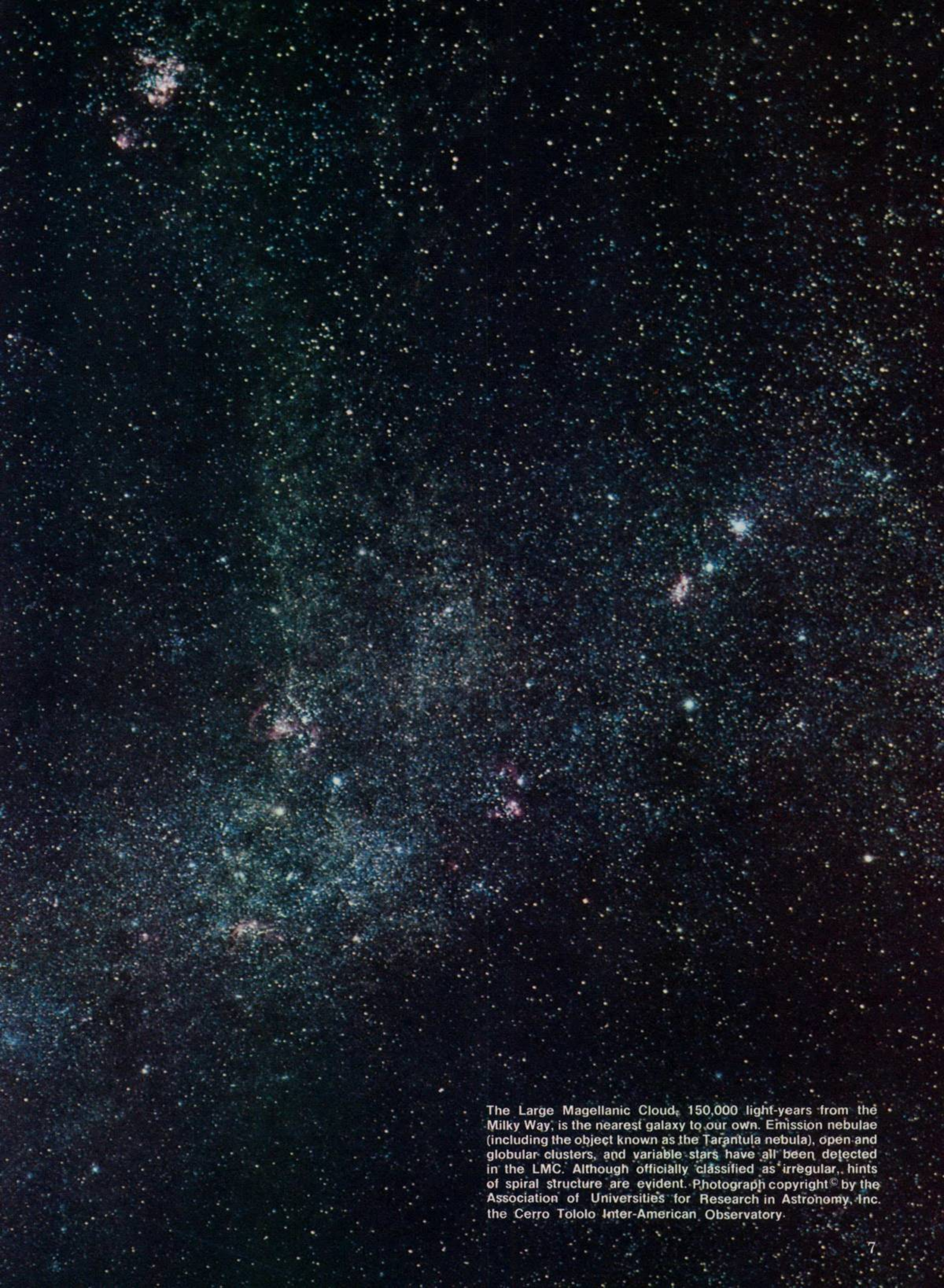
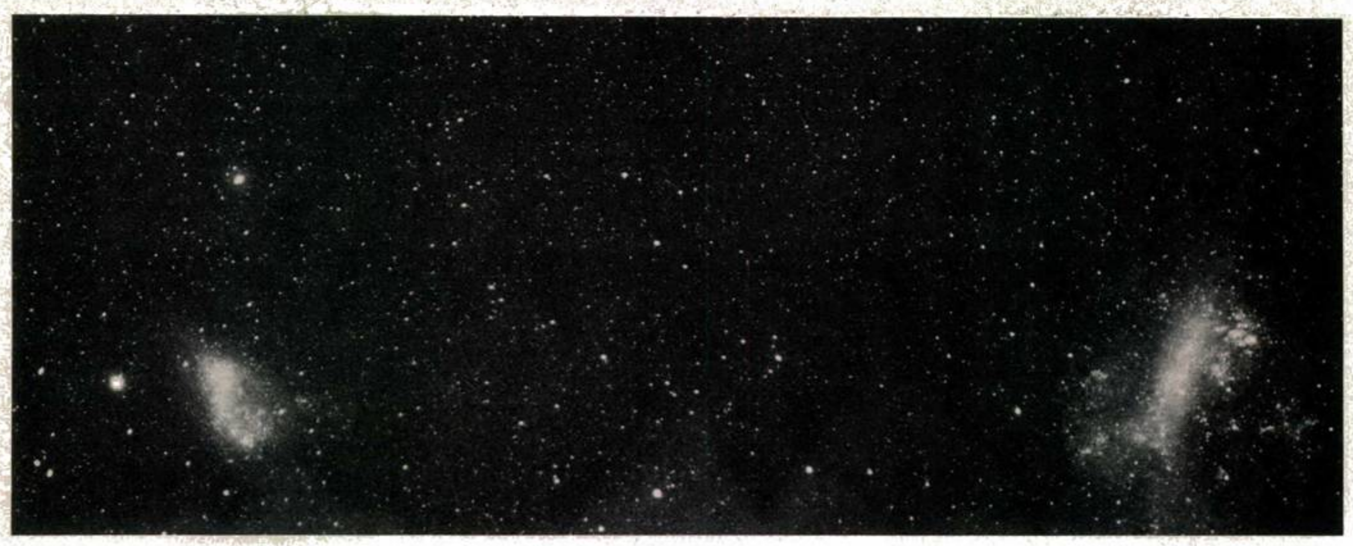
THE MAGELLANIC CLOUDS

by Gerrit L. Verschuur



The Large Magellanic Cloud, 150,000 light-years from the Milky Way, is the nearest galaxy to our own. Emission nebulae (including the object known as the Tarantula nebula), open and globular clusters, and variable stars have all been detected in the LMC. Although officially classified as irregular, hints of spiral structure are evident. Photograph copyright© by the Association of Universities for Research in Astronomy, Inc. the Cerro Tololo Inter-American Observatory.



In 1519, Ferdinand Magellan and his group of sailors set out in their fleet of five ships to sail around the world. Only one ship completed the trip, and Magellan himself died in a rather pointless battle in the Philippines. His historian, Pigafetta, was the first to officially describe the "clouds" that Magellan's men had seen; since then, they have borne the name of the famous explorer.

The Magellanic Clouds (MC) appear as two hazy patches of light in the dark skies near the south pole. You can't see them from the United States, but south of the equator they are easily visible to the naked eye on a clear night. Generally they are much more easily visible than the galaxy M-31 in Andromeda. But the Magellanic Clouds are, themselves, galaxies; they are simply much closer to our Milky Way than is the Andromeda galaxy.

The skies around the south pole contain few bright stars, and the dust clouds of the Milky Way add to the generally dark appearance of the sky. Thus, the clouds are easier to spot than they might otherwise be. There are only two stars of any brightness in their vicinity: Canopus (used as the prime star for orienting spacecraft) and Achernar.

At first glance the Magellanic Clouds resemble ordinary clouds, seemingly faintly illuminated, drifting overhead. They are not terrestrial clouds, however, but are enormous starclouds.

Magellanic Clouds are classed as *irregular galaxies* — a name that refers to their apparently disordered structure. Little sign of spiral arms or well-defined centers easily visible in other galaxies can be seen. The Large Magellanic Cloud does have a barlike region of stars within it. With a little imagination, you can see spiral arms emerging from the bar, but this structure quickly dissolves farther out.

The Magellanic Clouds are the nearest galaxies to our own Milky Way. But why should two galaxies be so close to our own Milky Way in the first place? Will they always be there? If they aren't much farther from us than some of the globular clusters — and they aren't — isn't it possible that they are merely some unusual objects that belong to our galaxy?

There are several possible explanations for the existence of the MC. The most popular suggestion is that they are satellites of our galaxy. In our universe, this is not an unusual situation; indeed, many other large galaxies are known to have small satellite galaxies orbiting them. M-31 has two obvious satellites, readily seen in photographs, as well as several fainter and smaller ones in orbit about it. If the clouds *are* satellites, they don't differ much from globular clusters — at least in the sense that the clouds and globular clusters would have formed from the same protogalactic cloud that became the Milky Way.

An alternative explanation is that the Magellanic Clouds are "visitors" from deep space, just happening to be passing near us. This is unlikely, however, in view of the small velocities the clouds have with respect to the center of the Milky Way. We would expect galaxies that happen to be passing by (like the proverbial ships in the night) to be traveling much faster than the clouds' 30 miles (50km) per second.

A third possibility is that the clouds are the remains of matter ejected from the center of our galaxy billions of years ago and now orbiting the Milky Way. Their ejection would have been the result of a violent explosion, similar to those seen in some other distant galaxies even now. Most astronomers subscribe to the first of these three theories — that the clouds are satellites — because it seems to be the most likely hypothesis.

In any case, we are fortunate in having the

A long bridge of hydrogen gas connects the Small Magellanic Cloud, photographed here, with its larger companion. The SMC contains a much higher proportion of interstellar hydrogen — perhaps 25 percent of its mass — than either the LMC or the Milky Way. About half the size of the LMC, the small cloud is 30,000 light-years more distant. Also seen in this photo is 47 Tucanae (NGC-104), a bright globular cluster. Cerro Tololo Inter-American Observatory photograph, copyright © by the Association of Universities for Research in Astronomy, Inc.

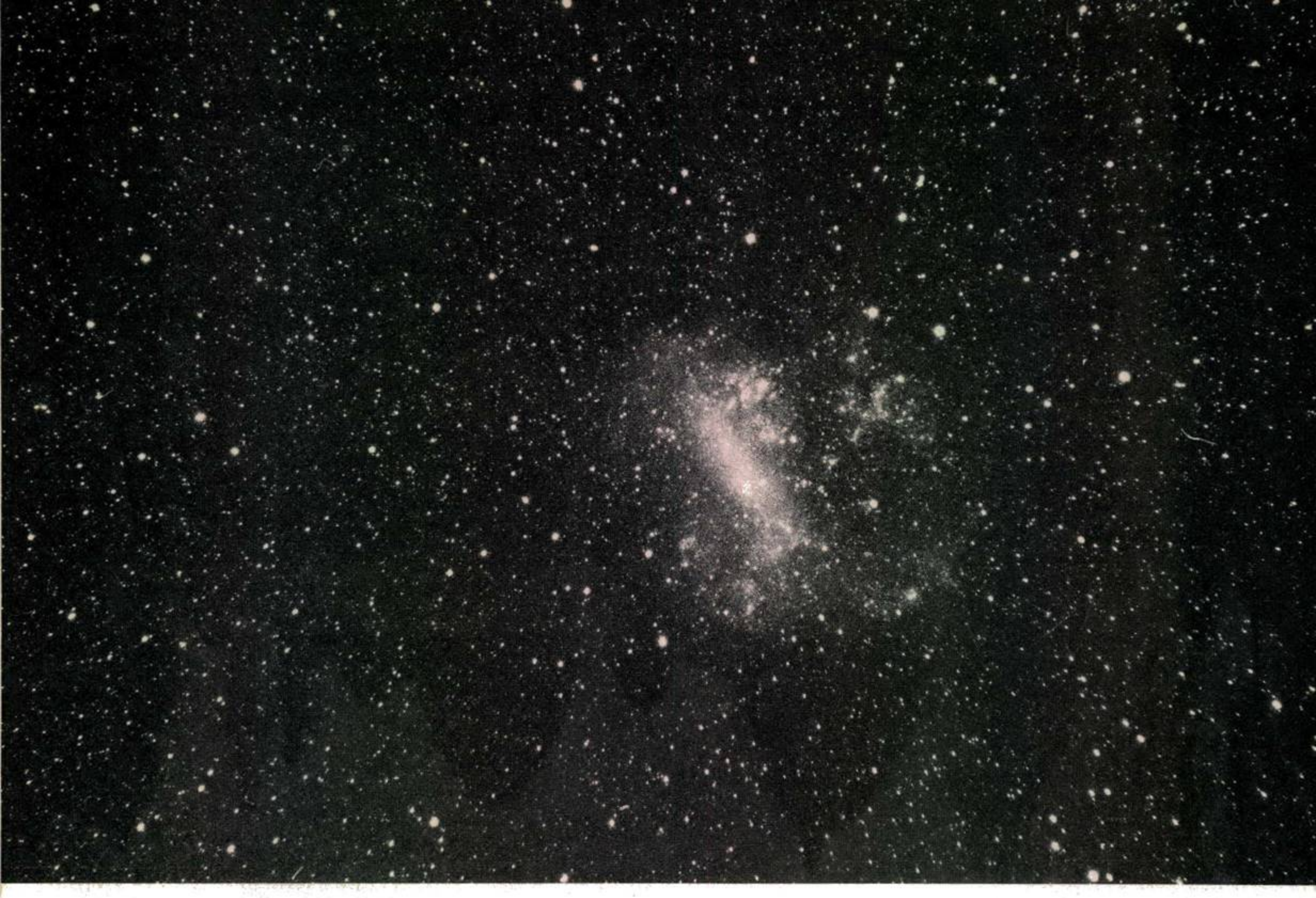
Magellanic Clouds so nearby, for they give us a clear, close-up look at two other galaxies. Unfortunately, since they are irregular galaxies, we can't learn much about the evolution of normal galaxies by studying them. Nevertheless, we can learn a great deal about stellar evolution by studying the stars in the Magellanic Clouds. In them, we have a sample of stars all situated at the same distance from us — an important fact to astronomers, and one that can help reduce the difficulty in measuring the distance of celestial objects. Based on the faintness of the hot young stars within them, we know that the clouds are very distant. Since the thickness of the clouds is small compared with their distance, we can reasonably state that all the stars within either cloud are at the same distance from us.

This concept was particularly vital in the earlier part of this century, when stellar distances were initially being measured. The Magellanic Clouds provided an ideal "laboratory" for studying stars — particularly Cepheid variables which are now used for distance measurements to distant galaxies. Harvard astronomer Henrietta Leavitt noticed that Cepheid variable stars in the Small Magellanic Cloud (SMC) seemed to have a period of variability that correlated with their apparent brightness. The brighter the star was, the longer was its period. Since all the stars were at very nearly the same distance from us, the differences in brightness could not be a distance effect. The phenomenon obviously had something to do with the properties of the stars themselves. Whatever determined their period also controlled their brightness, or vice versa.

The major features of the Magellanic Clouds can be photographed with any 35mm camera. Tri-X film was used to record the LMC (left) and the SMC (right) in two 15 minute exposures with a 50mm f/3.5 lens. The bar of the LMC is most prominent, followed by the many nebular regions to the right of the bar. In the SMC, shown at the same scale, only the stellar center is visible. Compare both pictures to the color Cerro Tololo pictures. Photographs by Chris Smith.

Even if one didn't understand why Cepheid variable stars varied at all, this discovery was exciting; clearly, some basic law that governed their behavior was operating. The next task was to find how bright Cepheids of a given period really were compared to how bright they appeared to be. This could be done by measuring distances to Cepheids using one of the various ways astronomers had of measuring distances to nearby stars — a task made difficult by the rarity of nearby Cepheid variables. Once the true brightness of Cepheids had been found and the period-luminosity law calibrated, astronomers could immediately look up how bright a Cepheid of a given period should be.

Returning to the Cepheids in the Magellanic Clouds, if one finds a Cepheid of a period whose true brightness is now known, it is an easy task to compare this with the measured brightness, in turn



allowing a distance estimate for the Magellanic Cloud Cepheid to be made. Hence, the distance to the Magellanic Clouds is found. The same trick can be applied to any other (observable) Cepheid variable as well — which is why Cepheids are used to measure distances to galaxies in which they can be resolved.

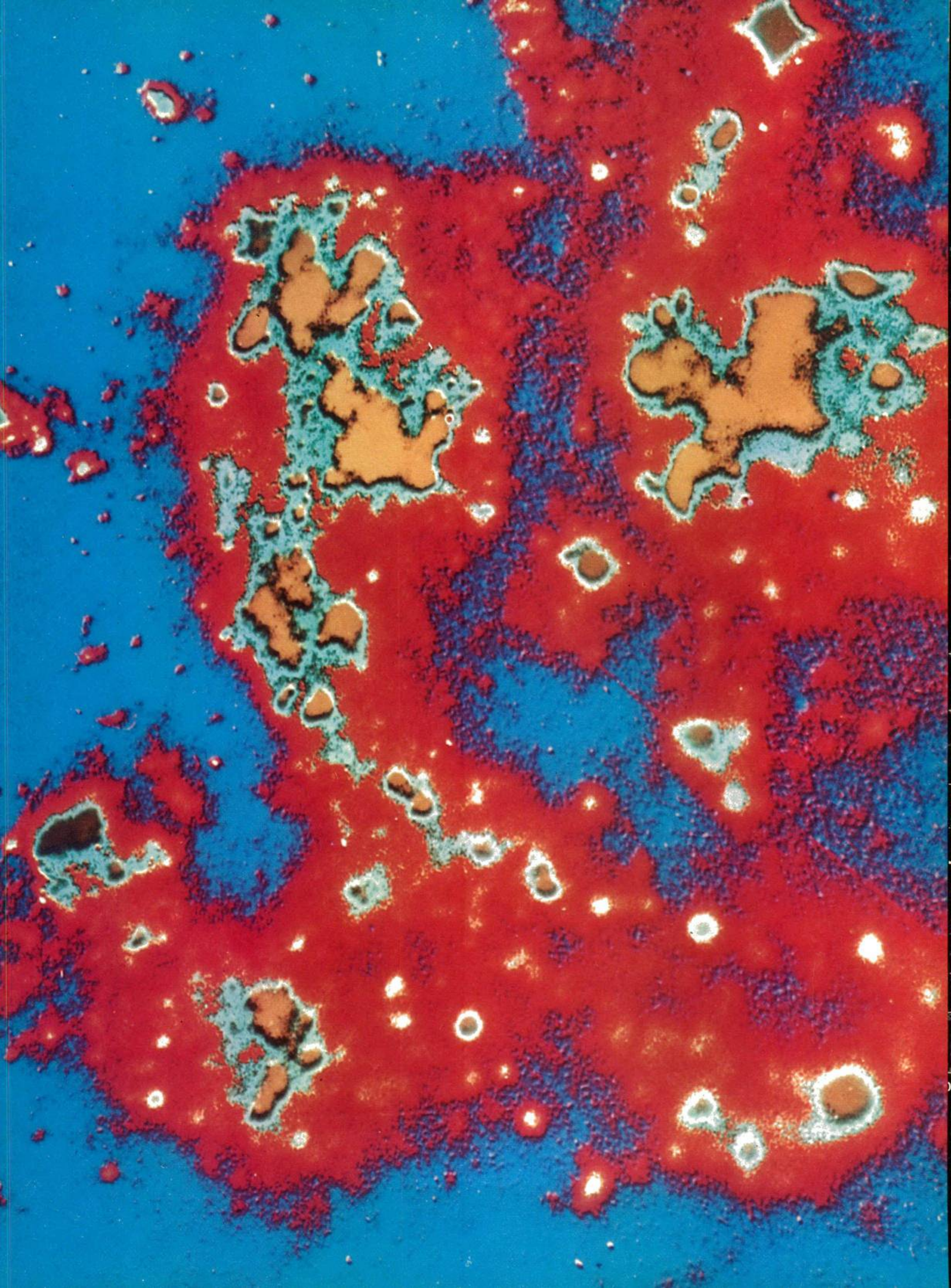
This great breakthrough gave astronomers a reasonably good idea of just how far away galaxies really are. Although distance measurement techniques have become much more refined since then, it was the early research work done on the Magellanic Clouds that paved the way for our present knowledge of the scale of galaxies and the universe.

The Large Magellanic Cloud (LMC) turns out to be 150,000 light-years away (compared with two million light-years for M-31). In fact, the LMC is so close to us that some globular clusters belonging to our Milky Way lie farther away than it does; at least one of the Milky Way's globular clusters is located no less than 200,000 light-years away. Since the diameter of our galaxy is 100,000 to 120,000 light-years, the Magellanic Clouds do not lie much more than a galactic diameter away. The SMC is 180,000 light-years distant — a bit farther away than the LMC.

The sizes of the Magellanic Clouds, as compared to our galaxy, are small. Our galaxy has a mass about 200 billion times that of the sun. The LMC, however, contains only 5 billion solar masses, and the SMC about 2-1/2 billion. Their diameters (as far as the clearly visible star distribution is concerned) are only eight and four degrees: about 24,000 and 12,000 light-years respectively. Our galaxy, when viewed from the clouds, would be spread over 40 degrees of sky. (For comparison, the whole constellation of Orion is about 15 degrees high.) Any astronomers who might exist in the LMC are no doubt having a wonderful time studying galaxy formation by looking at our Milky Way, even though they probably continue to be puzzled by their own system of stars.

The lack of clear spiral structure in the Magellanic Clouds is not so surprising when we consider the enormous pull of gravity our galaxy exerts on them. If the clouds have been in orbit about the Milky Way all their lives, they simply wouldn't have been able to evolve in peace, constantly subjected to tides from the Milky Way much as the moon produces tides on Earth. The effect is mutual, though; the clouds pull on the Milky Way is also seen. The outer parts of our galaxy show a bending (similar to a hat brim bent up and down), believed to be caused by the gravity of the clouds acting on the Milky Way.

A close look at the LMC reveals a somewhat bar shaped central region, reminiscent of the centers of barred spirals. A very bright emission nebula



Comparison of the Magellanic Clouds

	Milky Way	LMC	SMC	M-31 (Andromeda)
		Appearance		
* Distance	—	50 kpc	61 kpc	690 kpc
Angular Size	30 x 360°	8° x 8°	4° x 3.5°	2.5° x .70°
Magnitude	—	0.63	2.8	4.3
Hubble Type	Sb (?)	Irr	Irr	Sb
Inclination	—	27°	65°	77°
		Physical Characteristics		
Total Mass (in solar masses)	7×10^{10}	1.4×10^{10}	2.5×10^{9}	3.7×10^{11}
Diameter	25 kpc	6 kpc	3 kpc	33 kpc
Absolute Magnitude	—	-18	-16	-21

* 1 kpc (kiloparsec) = 3,260 light-years.

called 30 Doradus lies in the bar. It emits light and radio signals because it consists of hot gases. These gases are hot primarily because of the hot stars within the nebula. But the light and radio radiation from 30 Doradus also shows the existence of so-called nonthermal emission, produced by cosmic ray particles spiraling about magnetic fields — a phenomenon characteristic of nebulae that are the remains of supernova explosions. The combination of both types of emission is rare in one object. A similar phenomenon is also found in the center of our galaxy, from the radio source Sagittarius A; in fact, the overall properties of 30 Doradus are like those of Sagittarius A. However, 30 Doradus is not obviously at the center of the LMC; for that matter, the LMC does not even have an obvious center.

The clouds are also known to contain some extremely luminous stars. Most famous is the supergiant star in the LMC, known as S Doradus. This star, a million times more luminous than our sun, is the most luminous star known anywhere. It is also truly enormous — far larger than any of the giant stars (such as Betelgeuse or Antares) we know of in our Milky Way. It would certainly include the orbit of Earth within its confines, if it were to replace the sun in our solar system.

There are some very young globular clusters in the LMC. Some are younger than 100 million years, but globulars over 10 billion years old are also found there There may be as many as 10,000 clusters in the LMC, and virtually all are open clusters (similar to the Pleiades or the Double Cluster in our galaxy). This is an inordinately large number compared to the galaxy, in which only about 1,400 clusters have been catalogued. The clusters also usually contain more stars than do similar clusters in our galaxy.

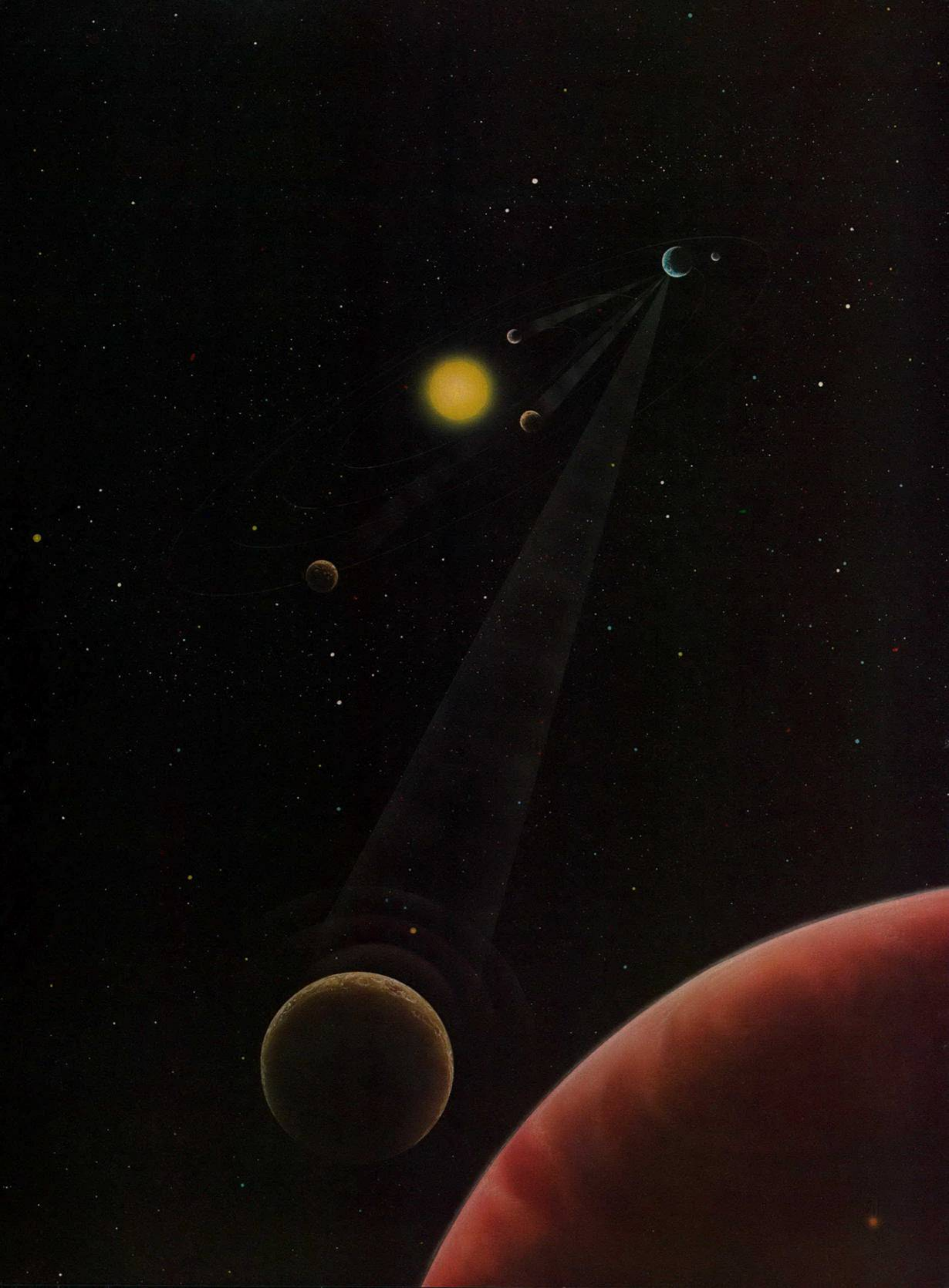
The Magellanic Clouds are littered with regions in which star formation has taken place. Stars appear to have formed in "pockets" and in time intervals lasting around a million years. The pockets cover areas about 3,000 light-years across, and seem to have formed about every two million years on the average. However, there appears to have been no underlying pattern to the process. These conclusions come from a recent study of the ages and locations of some 1,200 clusters.

The chemical composition and age of stars and gas in the clouds is basically similar to our own galaxy, and there is reason to suspect that life may have evolved equally well in the clouds as in our galaxy. In the Milky Way, interstellar hydrogen is situated in the spiral arms, while hydrogen in the clouds is very patchy in distribution. The LMC has about 50 important condensations of hydrogen gas in it — often associated with clumps of bright and young stars.

In addition to a bridge of hydrogen between the large and small clouds, there is an enormously long arm or stream of hydrogen gas stretching several thousand light-years into space from the clouds. Its origin is still unknown. Perhaps it is matter, left over after the formation of the Milky Way and the clouds, which never became concentrated enough to form stars.

Unfortunately for us, the clouds are not visible from any of the major northern hemisphere observatories. Consequently they have been studied with large telescopes only during the last few years. With the putting into operation of major new observatories in the southern hemisphere (in Australia and Chile), undoubtedly our knowledge of the clouds and the stars they contain will expand considerably in the years to come.

Shown in gaudy computer enhanced color, the Large Magellanic Cloud is strikingly different in ultraviolet light. The dark sky background is reproduced as blue, and red shading through green to yellow indicates increasing brightness. In this part of the spectrum, only very hot blue stars are recorded; the cooler reddish stars emit almost no ultraviolet light. This picture was taken from the surface of the moon during the Apollo 16 mission. NASA photograph.



RADAR ASTRONOMY

by

James Oberg

During most of its existence, astronomy has been a science based upon accidental evidence — totally dependent on light or radiation that managed to reach Earth, or upon pieces of meteors that survived our atmosphere. Despite the increase in knowledge, astronomy was hardly an experimental science.

In the past 30 years, this has changed markedly. Astronomers now deliberately send instruments deep into space to measure phenomena undetectable from Earth. If there are no pieces of other planets to study, scientists send spacecraft to the moon to retrieve them, or send probes to Mars and the Jovian moons — targets for an extraterrestrial rock hunt.

Part of this revolution — the field of active electromagnetic exploration — has largely occurred unnoticed, even though its results have provided some of the greatest surprises of the new era. The main areas of active electromagnetic exploration of the solar system are laser and radar astronomy. Laser study (so far) depends on precise mirrors placed on satellites, on the moon, and possibly (within a decade) on the surface of other planets and asteroids. Laser astronomy also depends on laser altimetry measurements made from orbit around the target world. Radar astronomy involves the transmission of powerful bursts of radio energy toward a target in space, and the receipt of the tiny echo bounced back to Earth or to a nearby spacecraft.

The history of radar astronomy was concurrent with the history of radar. European engineers detected the bounce of radio signals off Earth's ionosphere in the 1920s, and were puzzled by rare, long-delay echoes (LDEs) whose origin was and is obscure. During World War II, radar stations tracking enemy aircraft also tracked strange high altitude objects that appeared and disappeared, often in a pattern. They turned out to be the ionized trails in the upper atmosphere left by meteor passage. Three new major daytime meteor showers were discovered.

In 1946, several teams of scientists in America and Europe directed radar beams to the moon, and detected their faint echo. For the first time, a manmade effect had touched another world.

Power problems prevented any further advance for 15 years. Radar signals vary as the fourth power of distance, since the outgoing signal suffers an inverse square loss and the returning signal suffers an inverse square loss again. The power required to detect the moon was 1,000 times as great as that needed to detect an airplane 120 miles away — even though the moon is very much larger! Assuming the same radar reflectivity, engineers calculated that detection of another planet (Venus was the obvious target) would require an additional increase in power of over five million times — an increase which was then impossible.

Meanwhile, radars were built to keep track of artificial satellites circling Earth. Powerful radio antennas were built to send and receive signals for distant space probes. Radar sites devoted to immediate problems of space communications and national defense became more advanced and powerful every year. By 1961, these radar-gathering instruments had become powerful enough to begin interplanetary radar astronomy.

In 1961 and 1962, several teams of scientists around the world successfully received radar echoes from Venus, Mars, Mercury and the sun. Within a decade, echoes were detected from Icarus, Eros, Saturn's rings and Ganymede, and were being sought from comets, new asteroids and other moons. In some cases the signals originated from spacecraft orbiting the target world, and not on Earth. Radar astronomy had been established and accepted.

Just what does radar astronomy tell astronomers about a "target world"? Several factors are immediately obvious, but as techniques, equipment

Reaching out for — rather than passively receiving — information from the solar system is the essence of radar astronomy. Radar beams have probed the inner planets, yielding very precise orbits, and have uncovered the hidden rotation rate of Venus and the mistaken preradar rotation rate of Mercury. Mars' surface roughness at the Viking lander sites was checked by radar, and Jupiter's moons have been probed in the search for their composition. Artwork by Mark Paternostro.

and data reduction computation become more sophisticated, amazing new possibilities are opening up.

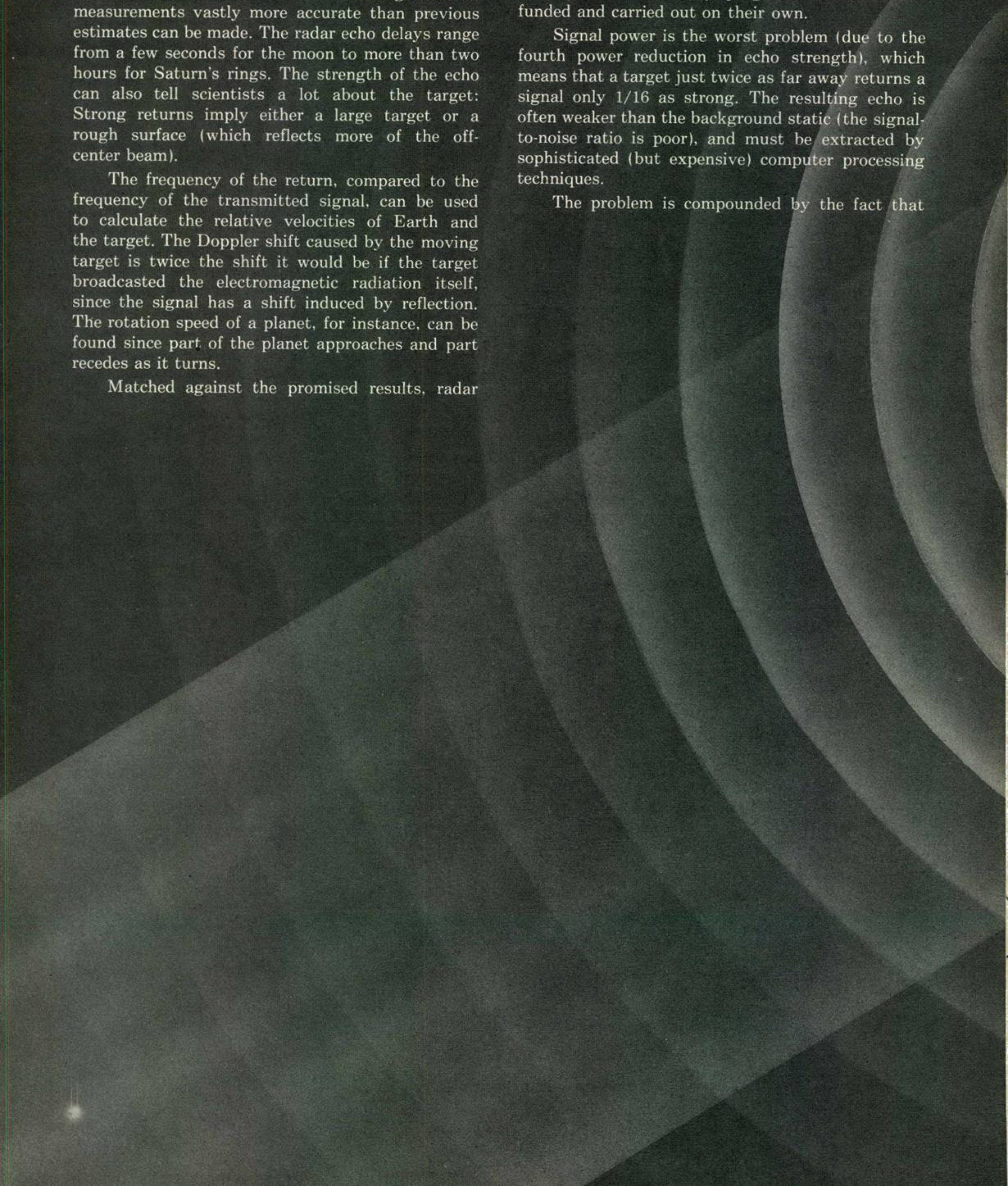
The first measurement obtained is the round-trip delay time, yielding the distance from Earth to the "target planet". Depending on signal duration (the accuracy of clocks at the receiving station), measurements vastly more accurate than previous estimates can be made. The radar echo delays range from a few seconds for the moon to more than two hours for Saturn's rings. The strength of the echo can also tell scientists a lot about the target: Strong returns imply either a large target or a rough surface (which reflects more of the off-center beam).

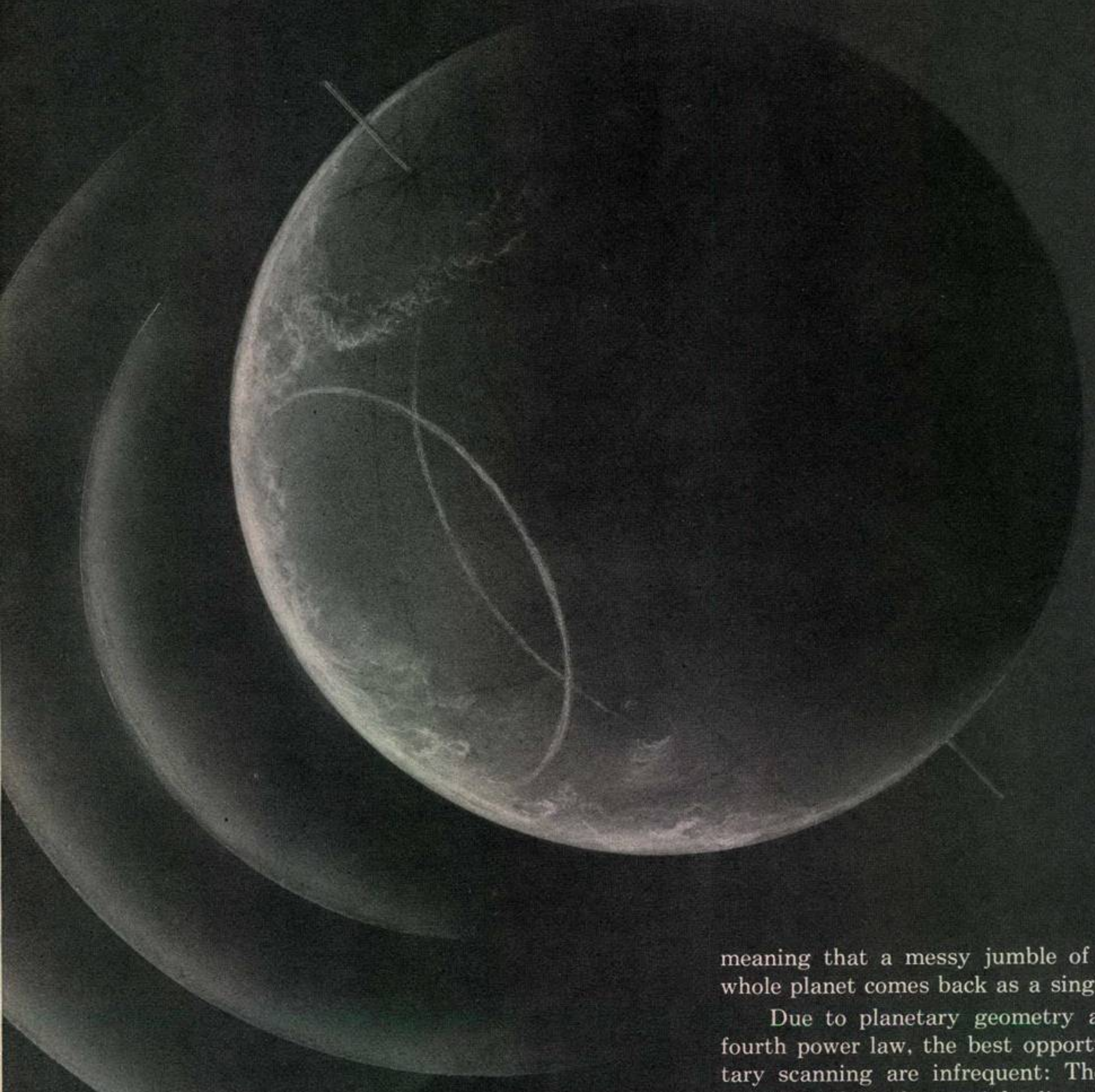
The frequency of the return, compared to the frequency of the transmitted signal, can be used to calculate the relative velocities of Earth and the target. The Doppler shift caused by the moving target is twice the shift it would be if the target broadcasted the electromagnetic radiation itself, since the signal has a shift induced by reflection. The rotation speed of a planet, for instance, can be found since part of the planet approaches and part recedes as it turns.

Matched against the promised results, radar astronomy faces tremendous technical problems. The cost effectiveness of radar astronomy has generally been so low that most radar astronomy studies are conducted piggyback by facilities built for other scientific jobs. Occasionally, however, special radar astronomy programs are conceived, funded and carried out on their own.

Signal power is the worst problem (due to the fourth power reduction in echo strength), which means that a target just twice as far away returns a signal only 1/16 as strong. The resulting echo is often weaker than the background static (the signal-to-noise ratio is poor), and must be extracted by sophisticated (but expensive) computer processing techniques.

The problem is compounded by the fact that





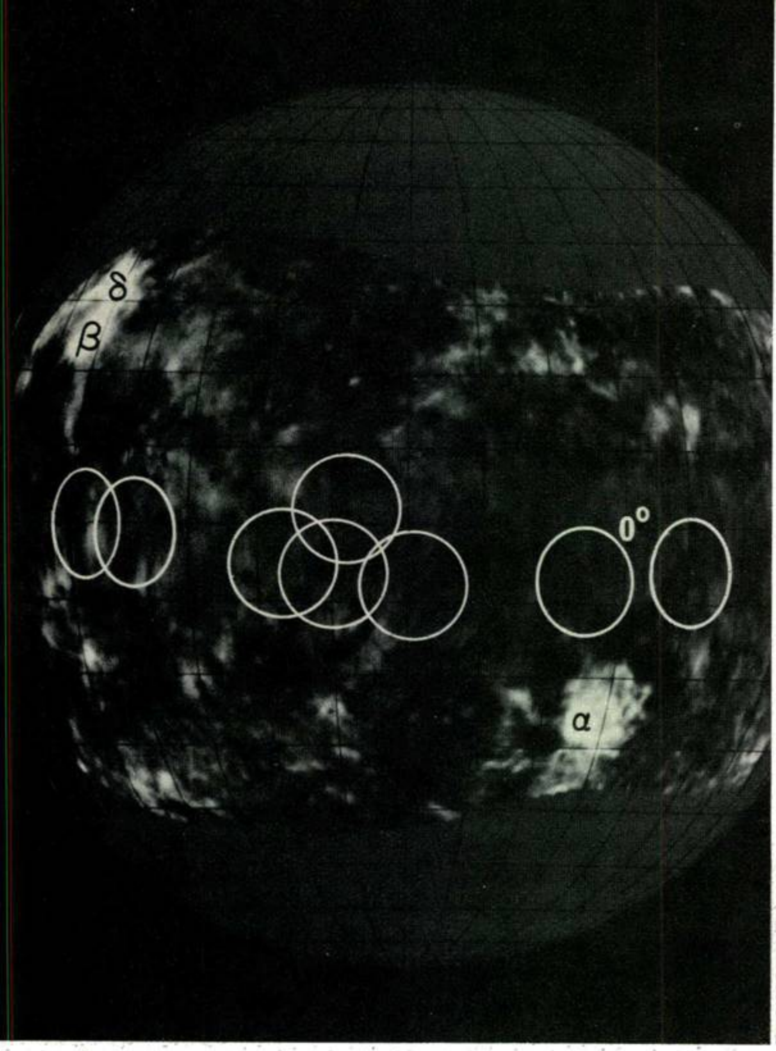
Radar bounces away from its target planet, carrying information about the planet's surface features and motion. Surface details can be located from analysis of the return signal, from the return time of the signal, and from the frequency shift in the returned beam. The ring on the planet's surface represents places having constant time delay; the short arc shows places having constant Doppler shift. On Earth, sophisticated analysis can yield the precise place on the planet that reflected the signal. Artwork by Mark Paternostro.

the universe is filled with such "noise" all across the electromagnetic spectrum. Additionally, there is the problem (but also the opportunity, as we shall see) of atmospheric distortion and absorption of the radar signal.

To add to the problems with signal power and noise, the beam from the transmitter spreads out enroute and bounces off the entire target planet — meaning that a messy jumble of echoes from the whole planet comes back as a single return!

Due to planetary geometry and the crushing fourth power law, the best opportunities for planetary scanning are infrequent: They occur at conjunction when the straight line distance between Earth and the target world is smallest. But since radar astronomy is usually a "secondary program" at most antenna facilities, and since an incredible amount of computer data time is required to decode the echo from an entire planet into a map, the delay between opportunities is not inconvenient.

Thus, the sophisticated techniques of radar astronomy have led to many of the most amazing answers and puzzling questions of the last decade. Radar astronomy measured the spin rates of Mercury and Venus and helped rewrite the texts on those planets. Radar astronomy has provided strong corroborating evidence that Saturn's rings and Jupiter's moon, Ganymede, are made of ice. It refined the yardstick of the solar system by giving incredibly accurate values for the astronomical unit. Radar bounced off the moon by Earth based and lunar-orbiting spacecraft have helped fill in the



Above left: A radar overview of the planet Venus is pictured with the circles representing previously shown areas (featured in ASTRONOMY, August 1976). Jet Propulsion Laboratory photograph. Above right: The lava flow Maxwell, named for its discoverer, is shown in a detailed version depicting surface variety which is impossible to see on the larger versions. Maxwell is a comparatively large feature and is approximately the size of Oklahoma. NASA photograph.

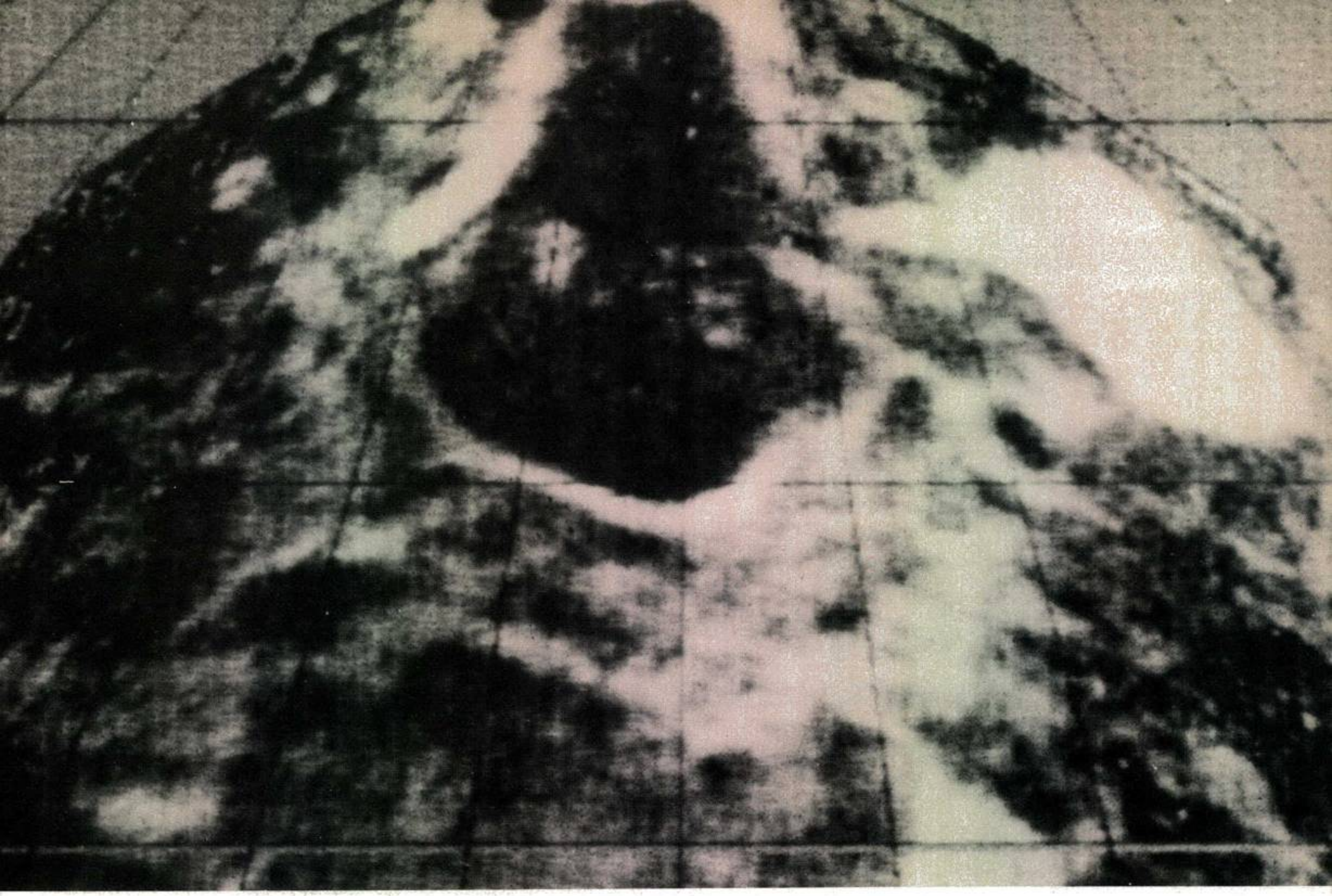
gaps left by the Apollo expeditions. Radar was used in surveying the possible Viking landing sites, and has been used to check the theory of relativity by tracking the advance of Mercury's perihelion and the retardation of radar waves near the sun.

The spin of a planet can be detected in one way, and utilized to map the world in another: As signals bounce off the receding and approaching limbs of the planet, the Doppler frequency spread of the echo carries information about the spin velocity independent of the relative velocities of Earth and the target. Once the spin has been measured, the induced Doppler shift can be used to determine surface features. But this effect must be used together with another technique called *Delay-Doppler Radar.*

Since the outer edge of the planet is farther from Earth than the sub-Earth point, returned echoes take longer to reach Earth. When measured precisely enough, the amount of delay can be used to determine how far the source of reflection is from the center of the planet. Combining Doppler and delay-time leads to the Delay-Doppler maps which can locate a source of reflection — to within less than 100 miles for Venus. But a problem remains: There is an ambiguity between echo sources north and south of the "Doppler equator". That is, two different places on the planet will both give the same delay and the same Doppler shift to a radar signal.

The resolution of this ambiguity requires further computer work or additional equipment. One technique, interferometry, makes use of a second receiving antenna at some distance from the main site; this has been used very successfully on Venus. A second technique, based upon only one antenna, takes advantage of solar system geometry in that the Doppler equator of a target may wobble 5 or 10 degrees over a few months. Separate observations, both ambiguous about a different axis, are made; computer processing is then used to separate out the north and south sites. (This works well for the moon but not for Venus.) The computer techniques used are very complex — in fact, the analysis would be impossible without rapid, large matrix manipulation hardware and software. A typical map involves solving several hundred thousand equations in several hundred thousand unknowns again and again.

The resulting image shows radar reflectivity across an area surrounding the sub-Earth point. The strength of the radar return, depending on the frequency of the radar beam, may tell scientists about the size of the surface particles, the elec-



Above: Three varied aspects of Venusian topography are evident. In the upper right portion is the lava flow Maxwell. The center portion features an impact basin which resembles maria in the moon. Ridges scattered through the photo may have been created by mountain building forces similar to those which formed on Earth. The photos were taken by the Arecibo Radar Observatory in Puerto Rico, with a new S-band system that increases sensitivity 50 times. NASA photograph.

trical properties of the surface, and the consistency.

Once the surface reflectivity has been charted, computer specialists go back to the original data for new calculations. The delay of the signals can be fine-tuned over the surface to determine the precise distance to the surface and the shape and topography of the planet.

Finally, the planet's atmospheric absorption of radar signals could be used to produce atmospheric density estimates — not just establishing an average planetary atmospheric value, but variations around the planet. Good estimates of altitude differences over the surface could have implications for internal planetary structure, crustal strength and composition. This technique, competing with planetary orbiting spacecraft, is still in the theoretical stage.

Lastly, a feature of the radar beam called "polarization" can be utilized to determine surface characteristics. A beam of electromagnetic light that is reflected has its polarization altered, except when it loses its polarization by many reflections. Therefore, areas of depolarized radar reflections are areas of extreme roughness on the planet's surface. Either result can be used to make "educated guesses" about the surface, which help guide new experiments and on-site exploration, as radar did prior to the Mars landings by Viking spacecraft.

In one aspect of on-site exploration, an orbiting spacecraft could catch radar beams from Earth that bounce off the planet's polar regions. Or, the spacecraft could transmit radar signals whose echoes can be picked up back on Earth. This type of experiment, which has already been applied to lunar studies, is one way to beat the inverse fourth power law. The most advanced experiment would consist of a satellite that both transmits and receives its own radar signals. Venus — with its murky atmosphere — is the obvious target for such a vehicle. Such a radar probe satellite is now under study for a powerful Venus-mapping satellite.

The field of radar astronomy still has many areas for improvement and still can make major contributions to the exploration of the solar system. Electronics engineers and mathematicians may not be typical astronomical workers, but their presence reflects both the high technological level of contemporary instrumentation and the urgent requirement for clever new data processing techniques. They are some of today's most far-ranging astronomy frontiersmen.

SKY ALMANAC

Four Planets Bring Year to Close

December Satellites of Jupiter
11:00 p.m. EST, 8:00 p.m. PST

1	4103	• •● •	16	42013	• • ●• •
2	2013	• ● • •	17	4103	• •● •
3	10234	•●•••	18	43012	• •● • •
4	30124	•●• • •	19	31204	• ••●•
5	32104	• • •● •	20	32014	• •●• •
6	32104	• •● •	21	3024	•● • •
7	30124	•●• • •	22	0234	●•• •
8	10234	• ●• • •	23	20134	• ●• • •
9	20143	• ● • ••	24	12034	••● • •
10	10243	• ●•• •	25	0134	●• • •
11	43012	• •● • •	26	31204	• ••● •
12	43210	•• ••●	27	3201	• • ●•
13	4320	• • •●	28	43102	•••● •
14	4301	• •● •	29	4032	• ● ••
15	41023	• •●• •	30	42013	• • ●• •
			31	41203	• ••● •

The four major satellites of Jupiter orbit the giant planet in periods ranging from just under 2 days to 17 days. They can be seen to change position from night to night. Sometimes their motions become evident after only a few minutes' observation. Only a small telescope is required to detect all four of the satellites and several can frequently be seen in rigidly held binoculars. This table shows the approximate positions of the moons at about 11 p.m. (EST) on the evenings indicated. First column on the left shows the date. Second column of numbers identifies the moons and their positions relative to Jupiter's disk. (1=Io; 2=Europa; 3=Ganymede; 4=Callisto, and 0= Jupiter's disk.) The third column approximates a telescopic view of the satellites' positions. The orientation of the satellites is shown inverted as seen in a standard astronomical telescope.

As the annual Christmas rush descends upon us and planetariums gear up for their yearly "Star of Bethlehem" programs, it is worthwhile to escape for an occasional night into the peace and beauty of the December sky. Several bright planets make for interesting and rewarding observing sessions; if you believe in spending Christmas Eve with the stars, the planets should make your evening more enjoyable before the warmth of the Yule log beckons.

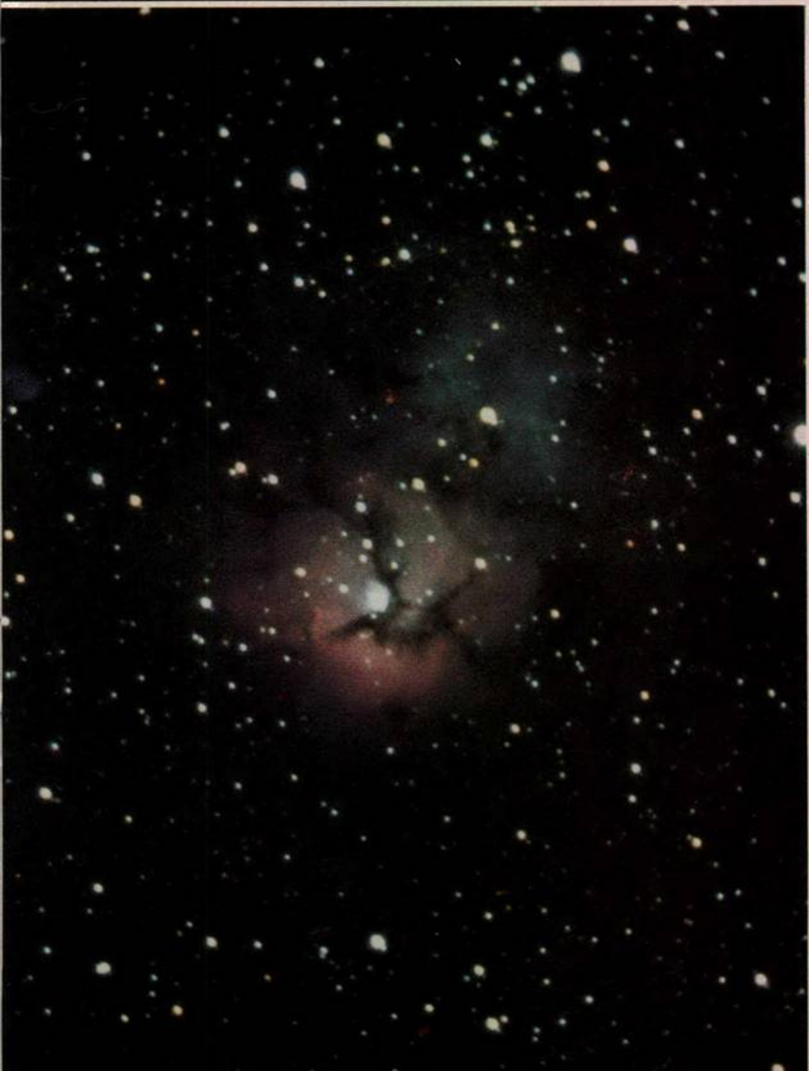
Mercury

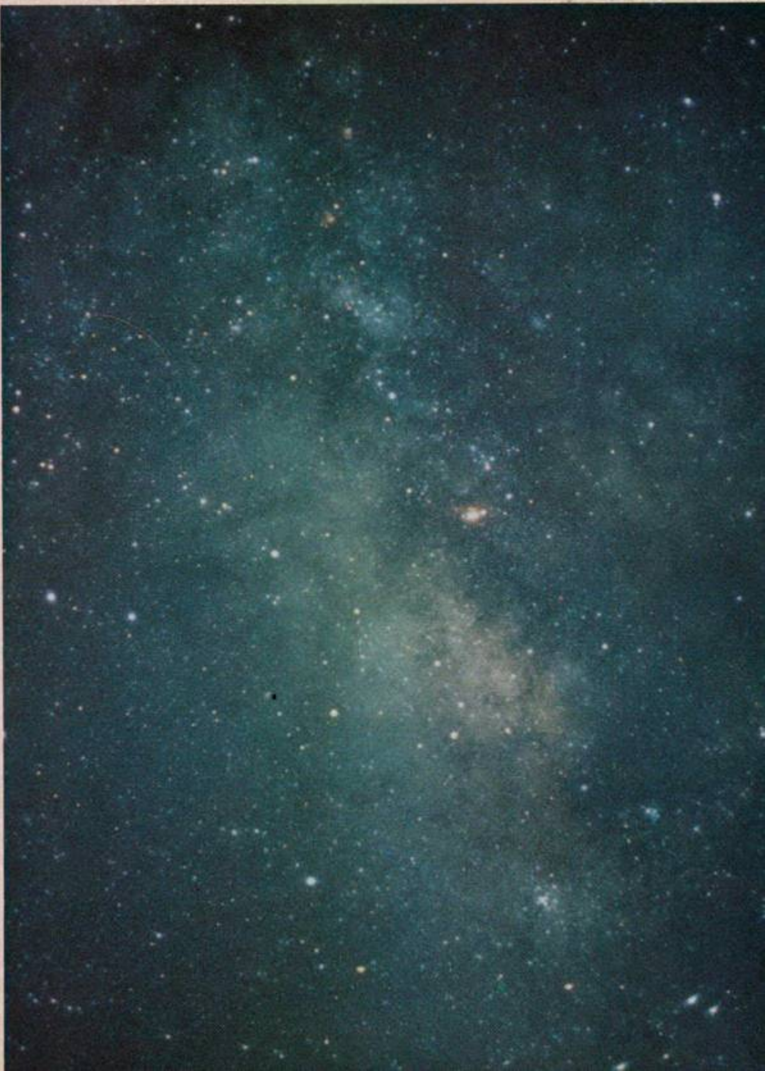
The smallest planet will shine at magnitude -0.3 when it reaches greatest eastern elongation on the 20th. Due to the low angle of the ecliptic over the horizon, however, this elongation will not present observers with a particularly good chance to observe Mercury, as it should be situated only about 10 degrees above the horizon at sunset. But if you have a clear horizon to the southwest, you shouldn't have much trouble finding it. Telescopes will reveal Mercury's gibbous phase on the 20th before the planet swings around in front of the sun, heading for inferior conjunction (between the sun and Earth) on Jan. 6, 1977.

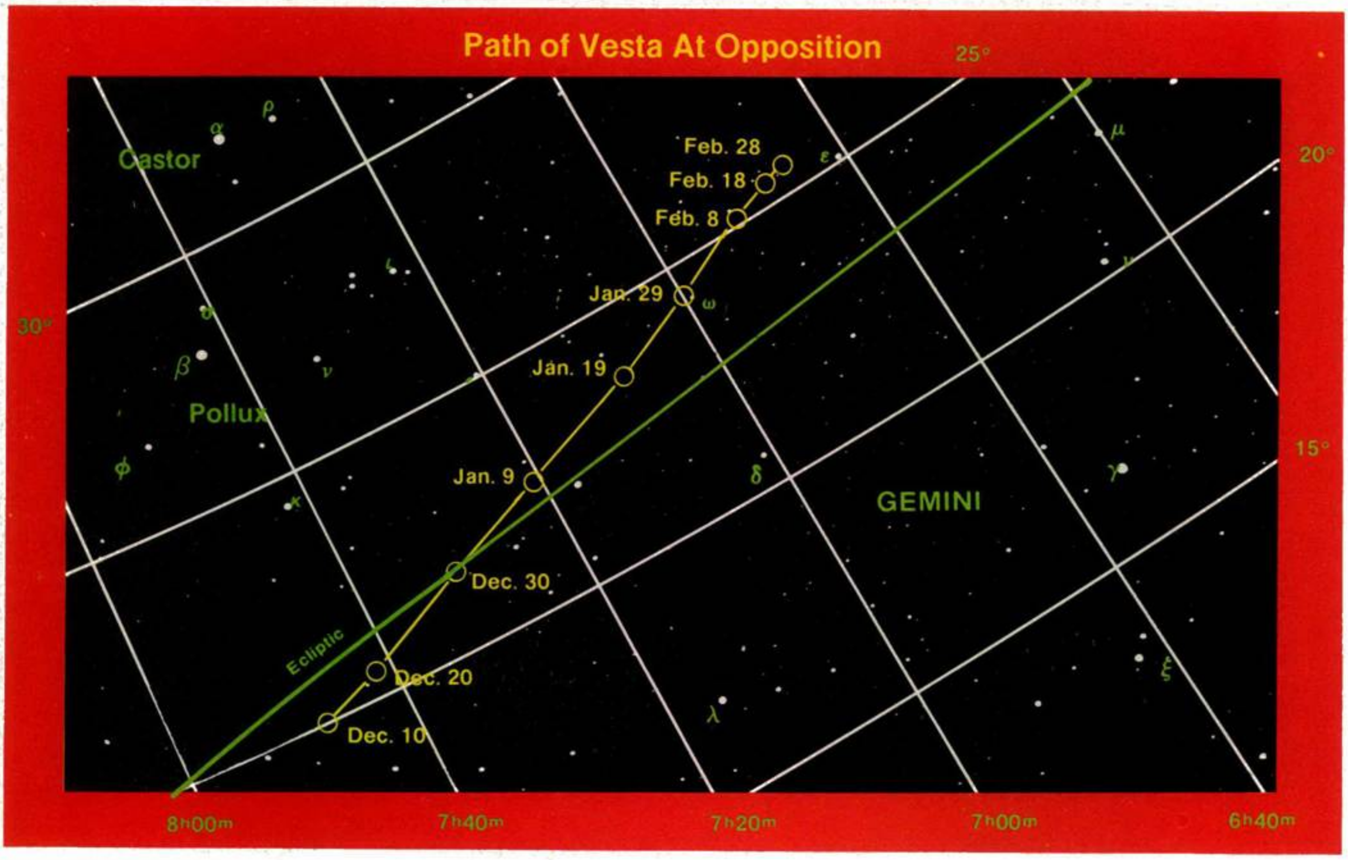
Venus

As it approaches its own greatest eastern elongation on Jan. 24, Venus continues to grow more brilliant. Its December magnitude of -3.7 easily outshines all other planets and stars. Since Venus will be visible for about three hours after sunset,

Upper left: This photo of the last quarter moon was obtained by the afocal method; a 4-1/2 inch f/8 reflector and 28mm wide field eyepiece were used. This is a 1/8 second exposure on High Speed Ektachrome. Photograph by Edwin Perley. Upper right: Comet d'Arrest was low in the south when this photo was taken on Aug. 29, 1976. GAF 200 film was used for this 30 minute guided exposure through a 200mm telephoto lens. Photograph by Bill Gordon. Lower left: This 20 minute exposure of the Trifid nebula (M-20) was taken with a cold camera on High Speed Ektachrome pushed to ASA 400, through an eight inch Schmidt-Cassegrain telescope. Photograph by Bill Iburg. Lower right: A 50mm lens at f/1.8 was used to obtain this striking photo of the summer Milky Way. This is a 3-1/2 minute exposure on GAF 500. Photograph by Howard Lazerson.







The 1976-77 path of the asteroid Vesta through the constellation Gemini is plotted on the map above. At brightest, the asteroid should shine at magnitude 6.6; opposition date is Jan. 9. Opposite: This stunningly detailed photo of the Mare Nectaris region on the moon was made through a 12 inch f/6 reflector. The large crater at bottom right is Theophilus; at upper left is Fracastorius. Note the pitted mare surface, which contains several "drowned" craters. Photograph by Robert Price.

December is a good time to compare it with Sirius, the brightest star in the sky. (Neophyte observers are frequently surprised at how much brighter Venus is than the star.) In a gibbous phase similar to Mercury's, Venus' diameter increases during the month from 15.6 to 19.2 seconds of arc, while its distance from Earth decreases from 100 to 80 million miles.

Mars

Just past conjunction, Mars is too close to the sun to be seen. This situation will last until about mid-February or early March, when the red planet will reappear dimly in the morning sky.

Jupiter

The giant planet is visible almost all night, having passed opposition last month. As Earth begins to draw away from it, Jupiter's diameter decreases from 45.2 to 42.6 seconds of arc, and both planets' motions increase their distance from 377 to 400 million miles apart. Its magnitude decreases slightly from -2.4 to -2.2. As its retrograde motion continues, Jupiter crosses the Taurus/Aries border into the latter constellation on Dec. 23.

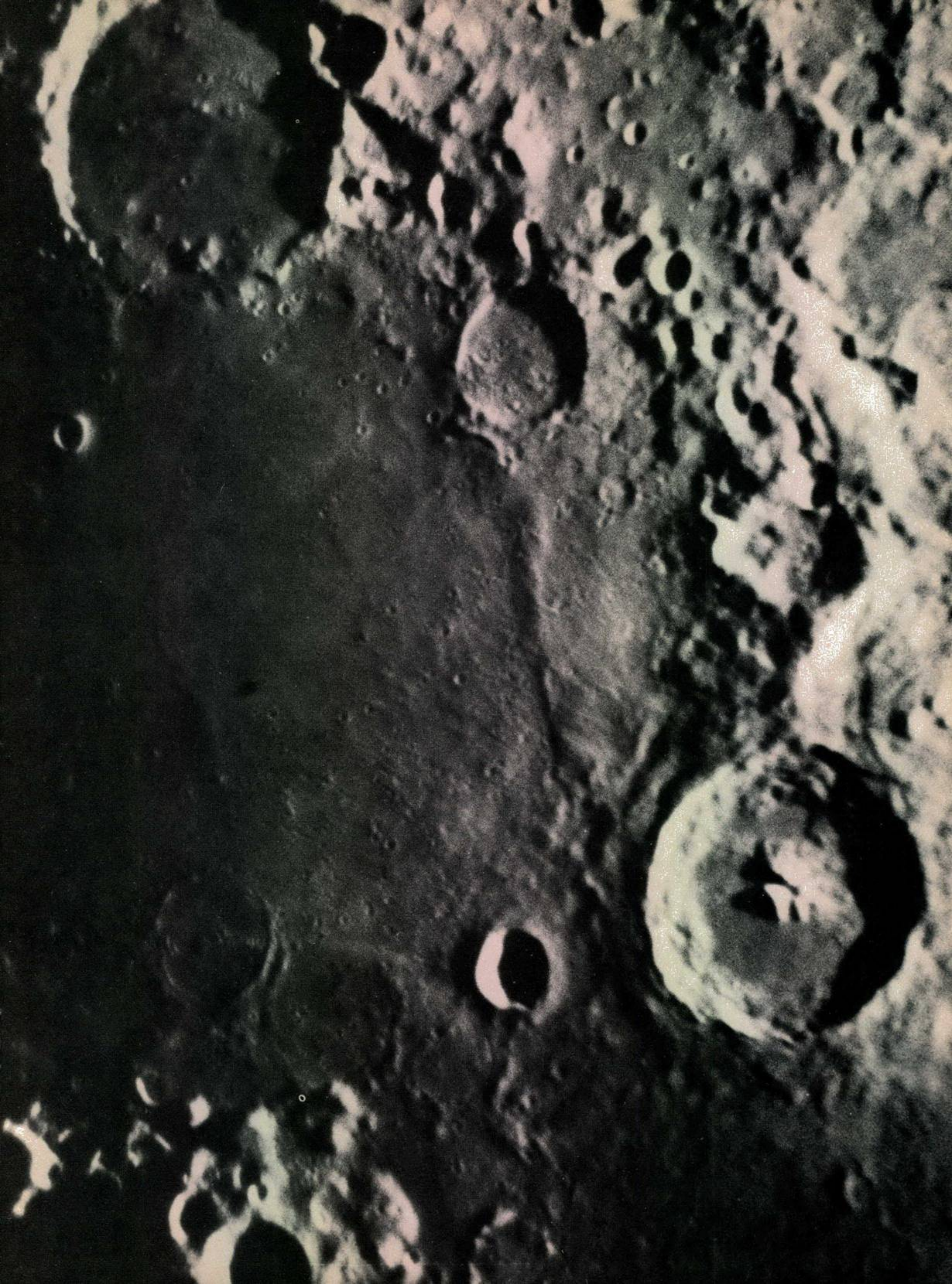
Saturn

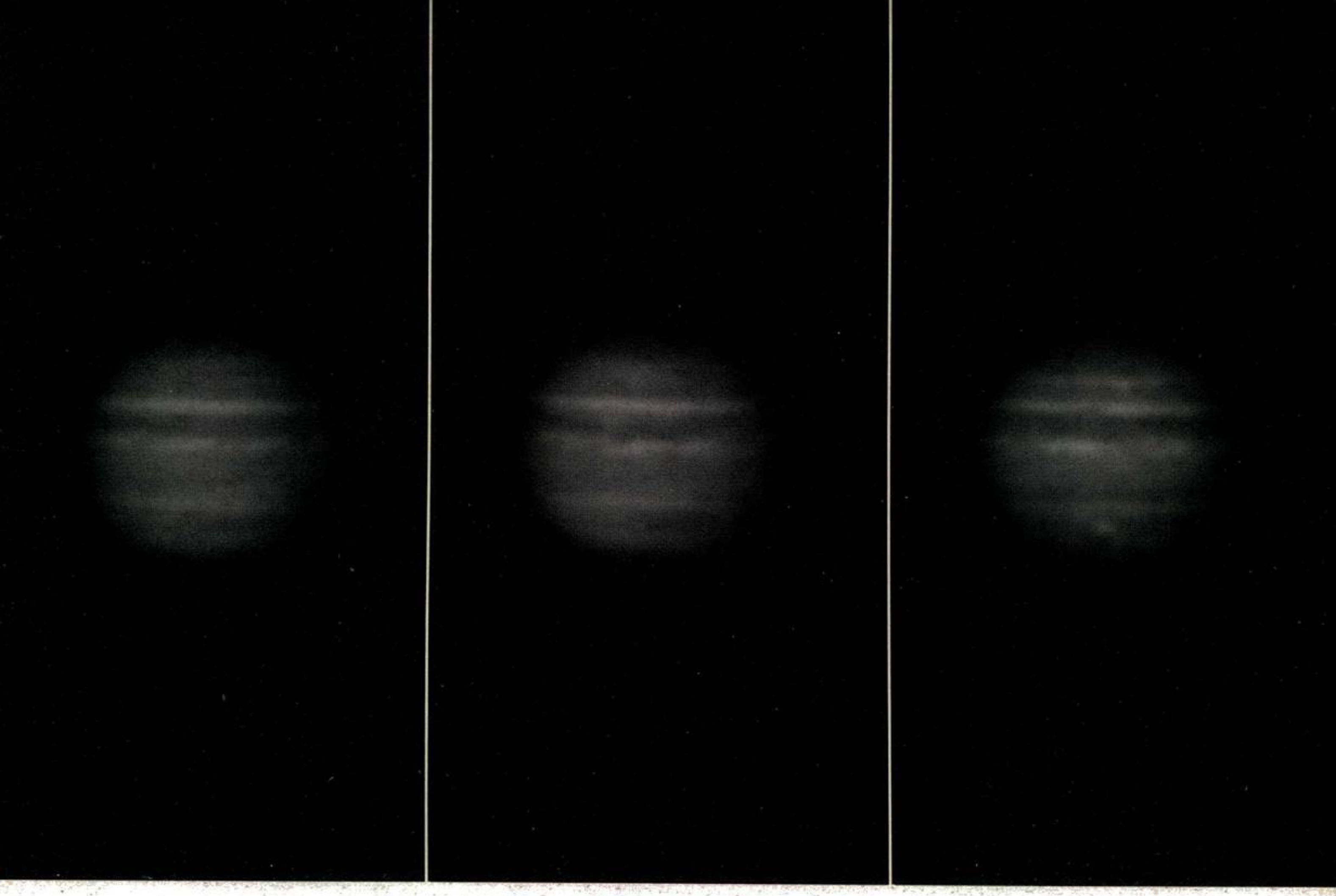
Located near the boundary of Cancer and Leo, Saturn creeps westward into the crab while moving retrograde. Brightening from magnitude +0.4 to +0.3 during December, Saturn's diameter increases from 17.1 to 17.8 seconds of arc. Saturn will reach opposition on Feb. 2, but is in an excellent position for observing during a period lasting about three months on either side of opposition.

Satellite Shadows on Jupiter

Date	Satellite	Transit Begins (EST)	Transit Ends (EST)
Dec. 1	1	3:16 p.m.	5:26 p.m.
2	2	12:21 a.m.	2:53 a.m.
5	1	4:14 a.m.	6:24 a.m.
6-7	1	11:43 p.m.	12:52 a.m.
8	1	5:11 p.m.	7:21 p.m.
9	2	2:58 a.m.	5:30 a.m.
11	3	5:25 p.m.	7:38 p.m.
12	2	4:16 p.m.	6:48 p.m.
14	1	12:38 a.m.	2:47 a.m.
15	1	7:06 p.m.	9:16 p.m.
18	3	9:26 p.m.	11:39 p.m.
19	2	6:53 p.m.	9:25 p.m.
21	1	2:33 a.m.	4:43 a.m.
22	1	9:02 p.m.	11:12 p.m.
24	1	3:30 p.m.	5:40 p.m.
26	3	1:27 a.m.	3:40 a.m.
26-27	2	9:30 p.m.	12:01 a.m.
28	1	4:28 a.m.	6:38 a.m.
29-30	1	10:57 p.m.	1:07 a.m.
31	1	5:26 p.m.	7:36 p.m.

1 = Io
2 = Europa
3 = Ganymede
4 = Callisto





Three photographs of Jupiter, taken only days apart as the giant planet neared opposition, exhibit perceptible differences in detail. Note the subtle variations in the cloud bands from one day to the next. From left to right, the photos were made on Sept. 14, 22 and 23, 1976; exposure times were seven, six and seven seconds respectively. All exposures were obtained on High Contrast Copy film, through a 14 inch Schmidt-Cassegrain telescope. Photographs by James K. Rouse.

Vesta

Vesta, known as the "naked eye asteroid", is rapidly approaching its Jan. 9 opposition in the constellation Gemini. Unfortunately, Vesta will not approach naked eye visiblity even at this date; it will achieve a magnitude no brighter than +6.6. The reason lies in Vesta's orbit: Few asteroids have orbits as close to circular as those of most of the planets; as a result, perihelion and aphelion distances (farthest and nearest to the sun, respectively) differ by a much greater proportion. In this instance, Vesta's opposition arrives near the time of its perihelion. It will therefore not reflect as much sunlight, and will appear dimmer than its maximum magnitude of about +5.7.

For those interested in viewing Vesta through binoculars or a telescope, or in photographing the small body, a map of its path near its opposition date appear on page 22.

Meteor Showers

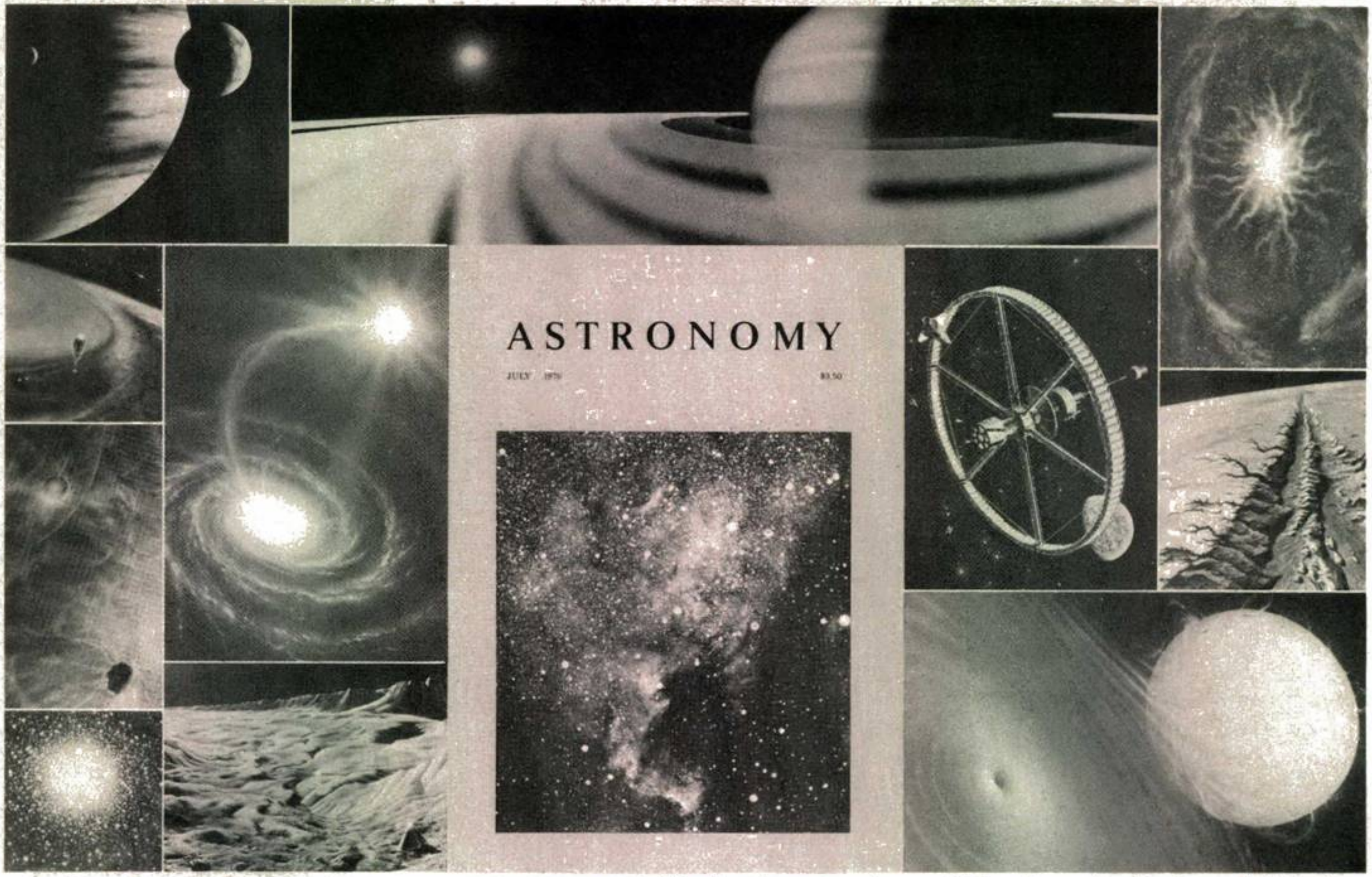
The Geminids and the Ursids round out the 1976 meteor shower season. The Geminids — second only to the Perseids in brightness, number and reliability — suffer the same fate this month that their brighter counterpart endured earlier in the year: The last quarter moon will effectively destroy any chance for worthwhile observation. Its glare will blot out all but the brightest members of this shower, which will reach its peak on the night of Dec. 13-14.

The Ursids — neither as dense nor as bright a shower as the Geminids — reach maximum on Dec. 22. Beacuse this is just two days after new moon, the Ursids should present a slightly better opportunity for skygazers who are determined to end the year with a good meteor-observing session. Radiating from near Beta Ursae Minoris, the Ursids' peak strength is about 15 per hour.

Winter Solstice

As it moves along the ecliptic in its annual path around the sky, the sun reaches its most southerly point within the borders of the constallation Sagittarius. This point, known as the winter solstice, is reached on Dec. 21 at 12:36 p.m. EST; winter will begin in the northern hemisphere, while people in the southern hemisphere will enjoy summer. After the solstice, the sun will revert to northward movement.

Man's Dream of Worlds Unseen



ASTRONOMY

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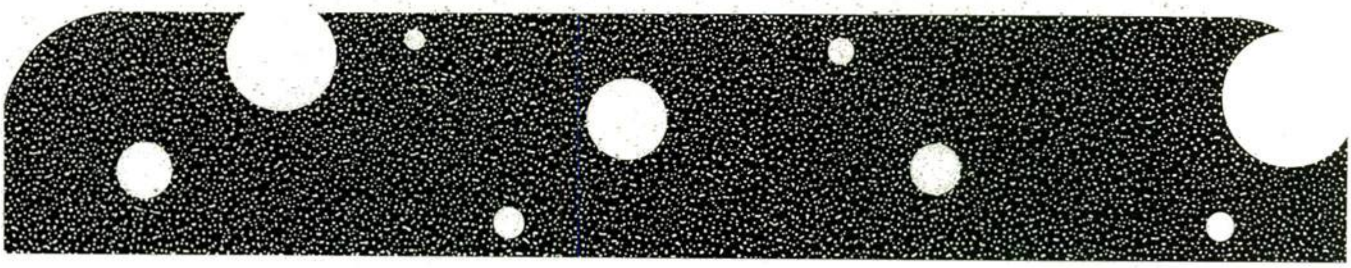


STELLAR FRONTIERS

Red Giant Stars

by

Bill Johnson

Stars come in all sizes and colors, from the emptiness of a black hole to the brilliant blue of Zeta Puppis supergiants. Stars are classified by their luminosity and surface temperature, and are placed accordingly on the Hertzsprung-Russell (H-R) diagram. A red giant, as the name implies, is a gigantic star with a cool outer envelope; its low surface temperature makes it red in color. Red giants include some of the most familiar stars in the sky: Arcturus, Betelgeuse, Antares, Aldebaran and Mira (Omicron Ceti).

Red giants are the product of stellar evolution. After a star completes its life on the main sequence, it changes into a giant star. There are, in fact, two types of red giants: those from the lower main sequence, and those from the upper main sequence. The difference between them is their mass. Stars at the lower end of the main sequence are less massive, and become *red giants*. Their mass must be less than 1.5 solar masses — otherwise they wouldn't become red giants. Those of masses greater than two to five (the dividing line is not precisely known) evolve into an extremely rare group: *red supergiants*. Stars between 1.5 and 6 solar masses somehow join one group or the other, apparently losing material if they are initially too massive to become red giants.

Upper main sequence stars spend less time on the main sequence because of their larger mass and luminosity. Massive stars are so luminous that they radiate their energy away, using up their hydrogen fuel much faster than smaller stars. Therefore, they run out of hydrogen to burn before the smaller stars do. (Stars do not actually "burn" elements nor leave "ashes" in the terrestrial sense, but it is the term most often used to describe how an element is used in nuclear reactions.)

Betelgeuse, a red supergiant, was once a blue star. In the first few million years of its existence, it used up most of its hydrogen, causing the radiation pressure which partially supported the star to weaken. Without this pressure to counteract the gravitational pull of the core, the star began to collapse inward, thus evolving into a supergiant. Since the core is compressed by the collapse of the outer envelope, the temperature around the core was raised. Hydrogen that had never previously reached ignition temperature began to fuse (a nuclear reaction by which nuclei combine to form more massive nuclei while releasing energy). Radiation pressure then halted the initial collapse of the star, restoring the internal equilibrium.

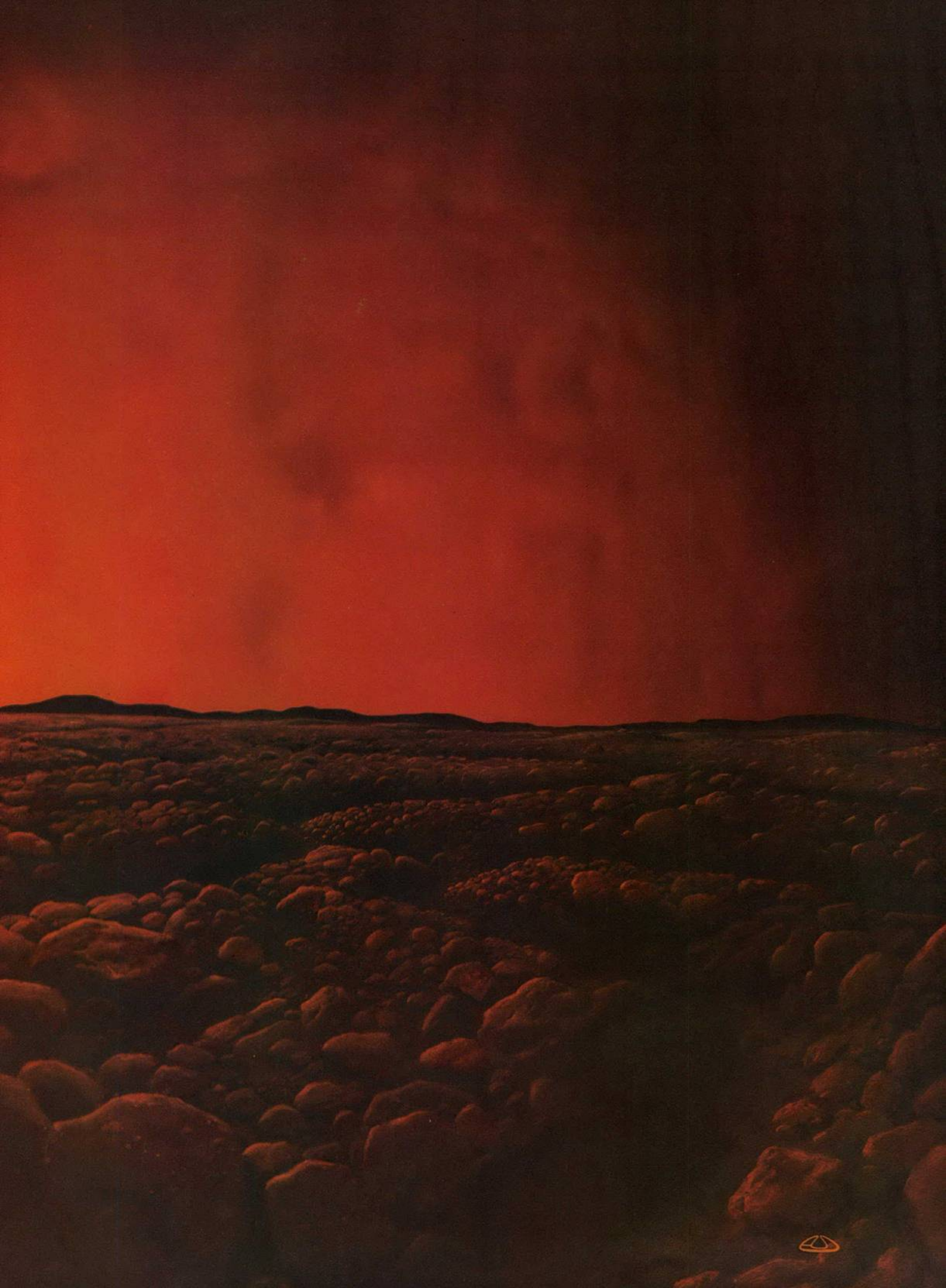
Eventually the "burning" hydrogen shell immediately surrounding the core also became exhausted, and the core began to collapse again. As the star's core continued to collapse, the upper layers of the infalling hydrogen were used for fuel, until it too was exhausted and a second fuel (helium) came into use.

Every time the core became hotter, the outer hydrogen envelope of the star expanded further. As the outer regions of the star expanded, they also cooled. Thus, the color of the star shifted toward the red.

The by-product of hydrogen fusion at the core is helium "ash". The ash accumulates at the core of the star, but it cannot fuse until a temperature and pressure far higher than that required for hydrogen fusion is reached. In massive stars, the gravitational collapse of the star does raise the temperature in the center of the core enough to begin helium fusion. Helium fusion begins in the core, while hydrogen fusion continues in a shell around the core. Radiation pressure forces the outer envelope of the star farther away, cooling it to a dull red heat. The star is now called a red supergiant.

Red supergiants are pulsating stars. As the

From H.G. Wells' *The Time Machine*: "The sky was no longer blue. Northeastward it was inky black. Overhead it was a deep Indian red and starless, and southeastward lay the huge hulk of the sun, red and motionless." Over four billion years in the future, a once friendly sun glows menacingly over the scorched remains of a deep ocean floor. This world, once dominated by life, has been sterilized by an unmerciful, monstrous red giant, and no eyes remain to gaze upon the scene. Painting by Adolf Schaller.



The iron fusion process of the red supergiant is portrayed here at the point of collapse, when there is more energy than the iron nuclear reactions can absorb. The core explodes, sending out a stream of ejecta that can total as much as half the star's mass. Artwork by Mark Paternostro.

inner shell of hydrogen depletes, the radiation pressure on the outer hydrogen envelope relaxes a bit. More hydrogen then falls on the core, and hydrogen burning revives. Thus, the star "burns" hotter and cooler in cycles, and the star's atmosphere expands and contracts.

Meanwhile, more helium begins to fuse, until finally the entire core is burning helium. Usually the core of a star would expand when the heat is raised as it is during helium burning, but the core of a red giant is so highly compressed that it acts more like a solid or metal than a gas. The core expands slightly when the temperature is raised, but not nearly as much as it would if the core was a gas.

Eventually, even the helium in the core of the star is exhausted. If the star is massive enough, the core will collapse until the temperature is raised enough to burn carbon and other elements. The star's outer envelope continues to expand, becoming duller and duller, until it reaches the point of a highly diffuse vacuum with an occasional excited atom.

The core of a massive star does not stop with carbon burning. After carbon has been exhausted, the core collapses again, performing the same procedure with oxygen, neon, magnesium, silicon, sulfur and finally iron. Other elements are also formed, but these are the major ones.

The crucial point is that nuclear reactions involving elements with a smaller atomic weight than iron *release* energy when fused together. Iron and the elements heavier than it *absorb* more energy than they release when they fuse.

When a core has collapsed to the point that iron fusion may begin, things happen very quickly. In a few seconds, energy-absorbing reactions remove

much of the core's heat. The core collapses on itself because there is no longer enough thermal radiation pressure to counteract gravitational attraction. Collapse raises the temperature of the core again, producing more energy than the iron nuclear reactions can absorb. The core explodes.

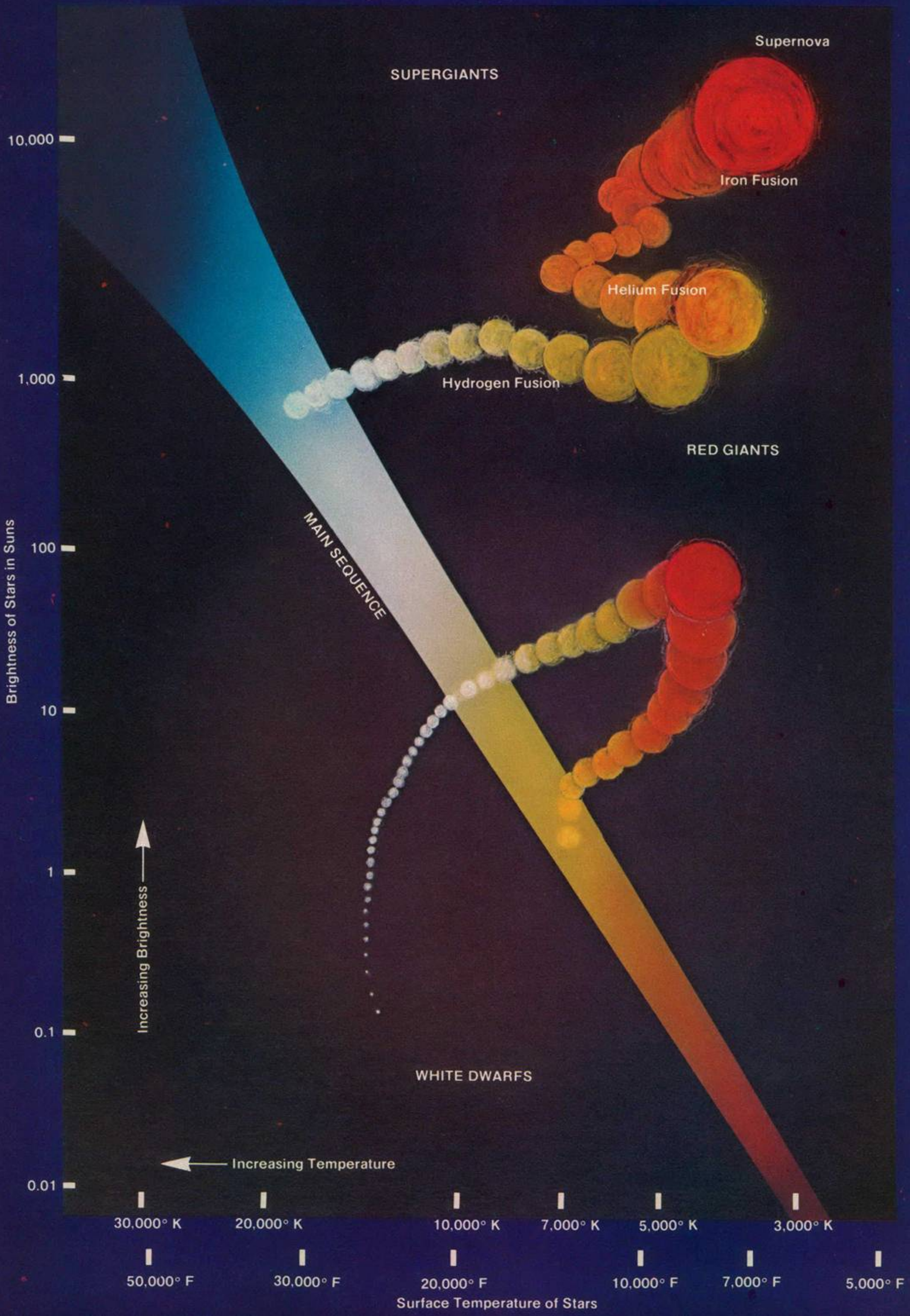
Supernovae are distinguished from ordinary nova by the much greater mass of material ejected: perhaps as much as half the total mass of the star. The star may be completely shattered, or the material that is left may begin to collapse on itself to become either a neutron star, or perhaps a black hole. In order to form a neutron star, the mass of the original star must be somewhere between 1.4 (Chandrasekhar's limit) and 3.2 solar masses, while in order to form a black hole, the theoretical limit is somewhere above 3.2 solar masses.

Most astronomers believe that massive red supergiants, through their final stage as supernovae, are responsible for the creation of all elements heavier than hydrogen or helium. All the material of our planet, then — except possibly for the hydrogen in the oceans — was possibly part of a red supergiant star before the formation of the solar system.

Not all stars are massive enough to form red supergiants. To become a red supergiant, a star must be above 1.5 times the mass of our sun. Stars with less than this mass (including our sun and most of the stars on the lower main sequence) have quite a different evolution.

Our sun, for example, is now over four billion years old, and is a typical star on the lower main sequence. A great deal of the original hydrogen at the sun's core has been used — perhaps as much as half.

Nothing dramatic will supposedly occur in the sun for the next four billion years while the core hydrogen is used up. It should continue to brighten and perhaps expand in size slightly. The increase in brightness will compensate for the drop in surface temperature that would be caused by the expansion


Supernova
SUPERGIANTS
Iron Fusion
Helium Fusion
Hydrogen Fusion
RED GIANTS
MAIN SEQUENCE
WHITE DWARFS
Increasing Brightness
Increasing Temperature
Brightness of Stars in Suns
10,000
1,000
100
10
1
0.1
0.01
30,000° K
20,000° K
10,000° K
7,000° K
5,000° K
3,000° K
50,000° F
30,000° F
20,000° F
10,000° F
7,000° F
5,000° F
Surface Temperature of Stars

of the outer envelope, so that the sun will maintain nearly its present surface temperature.

However, in another half billion years, the sun and its brightness (or luminosity) will increase by 50 percent over present, and its diameter will expand about 25 percent. By then, the sun will have exhausted almost all the hydrogen at its core. The helium "ash" at the core will have condensed into a ball at the center of the star (a helium core), but the temperature and pressure in this core would not have yet reached the point where helium can begin fusion. With only a thin layer of hydrogen fusion around the core, most of the core of that future sun will be a dead region.

The sun will rapidly grow in size until it is 2.5 times as big as it is now. The surface temperature will decrease. In the core the heat for hydrogen fusion in the outer layers is provided by the intense heat coming from contraction in the core. Eventually the core becomes degenerate — so compressed that it acts like a metal instead of a gas. Helium cannot compress itself more, and increases in temperature in the outer regions cause the core to expand only slightly.

As radiation pressure from the hydrogen burning shell around the core pushes the outer surface of the star farther and farther away, the core continues to collapse, providing more heat and radiation pressure which pushes the outer envelope of the sun farther and farther away. By then, the surface temperature of the sun will have dropped, and the color changed to the ruddy glow of a red giant.

Mercury's orbit will be swallowed. From Earth, the red sun would appear to cover 1/3 of the sky at noon.

Degenerate core material does not contract easily, but without any interior energy source to support the core, it must continue to shrink. Finally, at the center of the core the temperature will become great enough to begin helium fusion.

Helium fusion does not begin gradually in a lower main sequence star as it does in an upper main sequence star. The degenerate core is so tightly compressed that, as the helium at the center begins to fuse, the core expands only a little. The temperature throughout the core rises rapidly, because the core is more like a sphere of metal than a compressed gas. Helium fusion begins throughout the core instead of just at the center. Within a single day the sun will pass from the stage of beginning helium fusion to a stage of uncontrolled helium fusion. Called *helium flash*, the stage resembles nothing so much as an uncontrollable nuclear explosion.

Two stars are shown as they evolve away from the main sequence. The upper one, with a mass five times that of the sun, ends its career by becoming a supernova. The lower one has the same mass as the sun. After reaching the red giant stage, it cools and shrinks to become a white dwarf and ultimately a black dwarf. The band in the center is the main sequence — the band along which normal stars spend most of their existence. Artwork by Mark Paternostro.

Helium flash will drastically change the composition of the interior of the sun, but this will not be immediately visible on the surface of the star. The hydrogen shell around the helium core (which until the helium flash provided most of the energy for the sun) will be blown apart. Without the hydrogen burning shell, the core will drop rapidly in temperature as it expands, causing the sun to actually drop in brightness.

Our red giant sun will become smaller and less bright, but its surface temperature will again increase. Its energy provided by the helium burning core and an outer, hydrogen burning shell, the sun will move back toward the main sequence.

Eventually the helium at the core will be exhausted and the sun will again increase in brightness, increase in size, and decrease in temperature. Instead of a helium core, the sun will have a core of carbon and oxygen, the waste products of helium fusion. Evolving in much the same way as it did before helium fusion, the core will contract, the heat of its contraction igniting the outer layers of helium and hydrogen, and in turn forcing the outer envelope of the star away. Once again the sun turns back into a red giant. Eventually the pressure at the core of the star ignites the carbon, and a carbon flash, much like the earlier helium flash, disrupts the outer shells.

This is probably the last time the star can become a red giant. At this point there is not enough mass to collapse and burn the residue of carbon fusion. When the carbon burning phase ends, a lower main sequence star will collapse for the last time.

Collapse brings about the formation of a degenerate core, surrounded by a shell of hydrogen-helium that continues fusion. As this shell is exhausted, it collapses on the core. As time passes, more and more of the star collapses on the core, which slowly begins to change.

Since not enough mass is left in the star to overcome the repulsive forces between electron and proton, the sun cannot eventually form neutronium as neutron stars do. The sun will never become a neutron star. When the last of the star has collapsed into the core, the resulting star is a white dwarf.

A white dwarf is a very stable star. Its heat and light are provided by the gravitational energy of its collapse. A star the size of the sun will collapse into a white dwarf little bigger than Earth. But even white dwarfs die, though very slowly. Eventually the gravitational energy of the white dwarf is exhausted and the star cools. When it descends below a certain level of temperature and luminosity, a white dwarf is called a black dwarf — the end point of all lower main sequence stars; a dark crystalline ball the size of Earth.

GAZER'S GAZETTE

The Messier Catalog: Taking A Second Look

by
Henry J. Phillips

Let's assume you've owned your first telescope for a couple of years. Whether it's large or small, refractor or reflector, you've been eager to make good use of it without quite knowing where to start. After a few looks at the moon and planets, you remembered that quite a few of the sky's showpieces — stunning photographs of which are in all your astronomy books — are included in something called the "Messier list". You decided to try what other observers have done: Find, and look at, every object on this list.

Finally, you're finished; you've located all 105 objects. You've gone into ecstasies over some and been keenly disappointed in others; you've found some on your first try, and located others only after long hours of frustrating search. At last you've reached the end of the list, and after placing your check mark next to the last number, you sit back and bemusedly think: Now what?

At this point you're unlikely to take very kindly to any suggestions that you start over and do the whole task again. But stop and think a minute. How many of the Messier objects did you really look at closely, and how many did you find just for the sake of finding them? How carefully did you study each object (especially the dimmer ones), and how often did you go back for a second look — if at all? What is this Messier list and what purpose does it serve?

Various lists of "nebulous stars" existed before Charles Messier compiled his catalog of clusters and nebulae in the second half of the 18th century, but these other lists were usually prepared as appendices to star catalogs, not entities in themselves. Such lists were often made without the use of a telescope, and included asterisms or nonexistent objects; most are notoriously unreliable. Messier's list was the first accurate catalog of nonstellar objects available to both scientists and amateurs. Later observers have prepared far more systematic catalogs: Sir William Herschel, for example, placed every nebula or cluster he found into one of eight different categories. And yet Herschel's catalog is virtually unknown today, while Messier's continues to be the standard list of the brightest or most accessible objects, despite its haphazard quality. Why?

First of all, the Messier list presents the observer with a limited objective. There are only a little over 100 objects on the list — a number small enough to prevent intimidation at its extent, but large enough to provide a good deal of variety. Second, the very randomness of the catalog is part of its attractiveness. If all the globular clusters were numbered consecutively, for example, or if the objects were placed in order of right ascension, the list would certainly be more straightforward — but would lose a good deal of its charm. There is something indefinably enjoyable about the way the numbers jump all around the sky in no particular order.

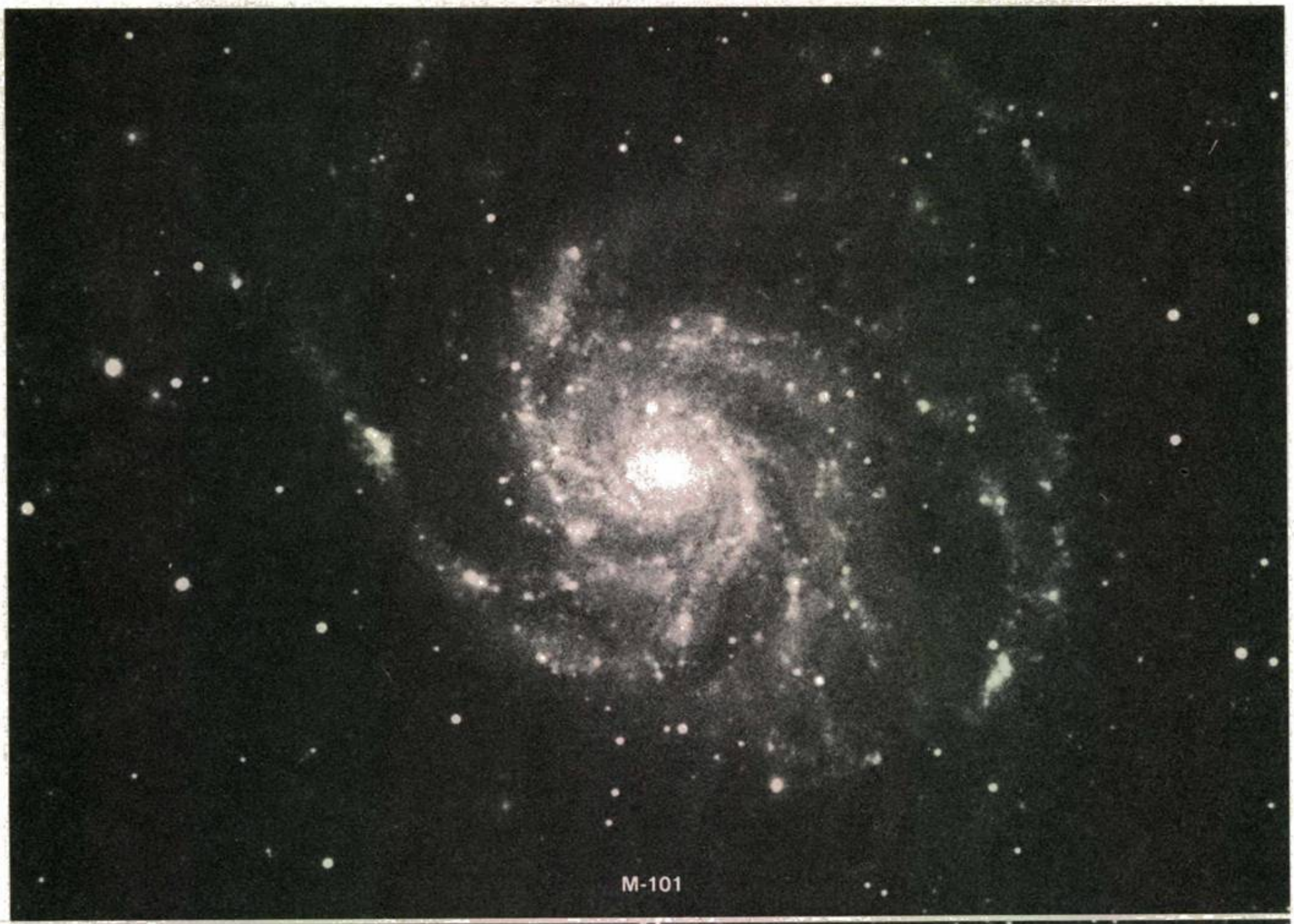
Finally, as we've already mentioned, the majority of the sky's most spectacular and beautiful objects are on the list, encouraging the observer to inspect those which are less bright or exciting, and to go on from there to items that are not on the list at all. There is perhaps no more useful way to learn your way around deep sky objects, and to know what to expect from them, than by charting your way through the Messier list.

Before beginning your second journey through the Messier catalog, therefore, take a little time to study what it includes — what kinds of objects, their shapes and brightnesses, sizes and distances — in order to become aware of what you're going to see the second time around.

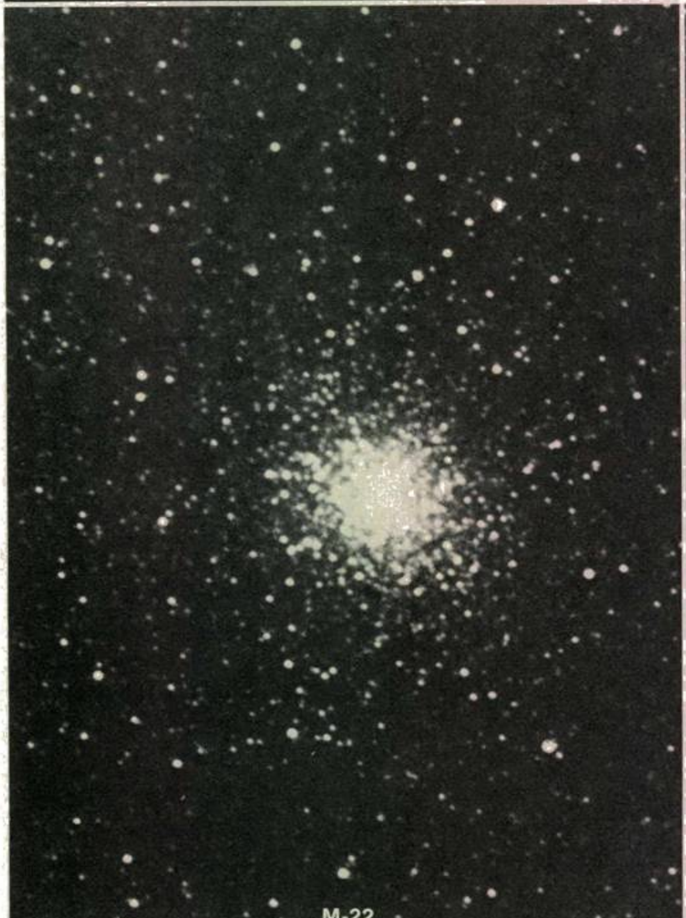
Planetary Nebulae

Over 1,000 planetary nebulae have been dis-

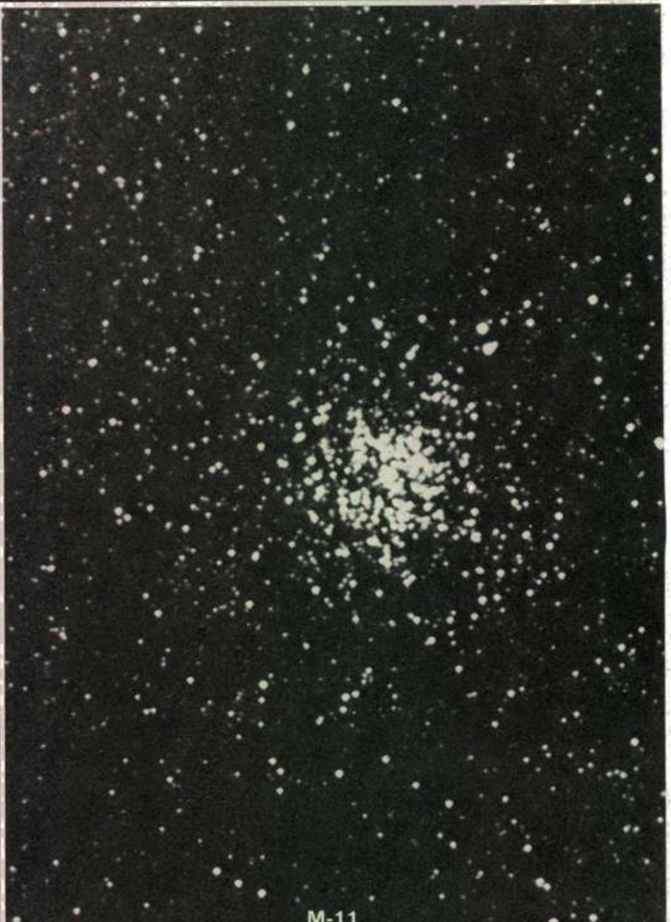
M-101: Photograph by Evered Kreimer. M-22 and M-11: Photographs by Christopher Bowland.



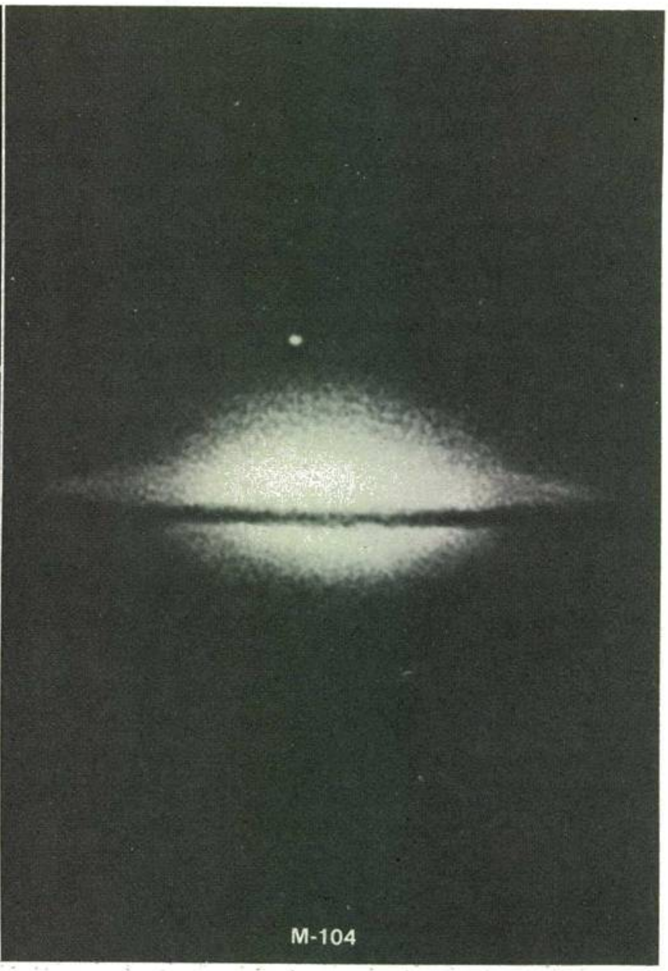
M-101



M-22



M-11



M-81 and M-82: Photograph by Greg Griffith. M-104: Photograph by Clarence Custer.

covered in the Milky Way, but most are extremely small, faint and hard to spot. Messier included only four on his list: M-27 in Vulpecula, M-57 in Lyra, M-76 in Perseus, and M-97 in Ursa Major.

Despite their name, planetary nebulae have nothing to do with planets. They were named by Sir William Herschel, who noticed that many of these objects exhibit pale greenish disks, quite like those of true planets. In fact, planetary nebulae are expanding shells of gas thrown off by small, hot stars. Often, this expanding nebulosity takes on strange — even bizarre — shapes, and each of Messier's planetaries has received a nickname derived from its apparent shape. M-27 is the Dumbbell nebula; M-57, the Ring; M-97, the Owl; M-76, which bears a slight resemblance to M-27, might perhaps be called the Barbell nebula.

M-27, the brightest of these four objects at magnitude 7.6, is quite prominent in the summer Milky Way. M-57, though smaller and fainter, is even more distinctive, glowing like a faint smoke ring. Messier suspected that the Ring nebula was "composed of very small stars", although he was the first to admit that even the best telescopes could not distinguish any.

M-76, on the other hand, is the dimmest object on the entire list, and M-97 runs a close second; both are 12th magnitude. Messier himself stated that both were extremely hard to see. Considering the small aperture of most of his telescopes, it's surprising he was able to pick them up at all!

Diffuse Nebulae

Messier lived and worked long before the age of photography, and could have no way of knowing about the many bright clouds of gas that filter through the extensive reaches of the Milky Way. Only the brightest of these were accessible in his telescopes, and only seven got onto his final list of objects. Most of these are associated with clusters of stars, and Messier usually described them that way. M-8 (the Lagoon nebula in Sagittarius) is described as a "star cluster which appears as a nebula when seen in an ordinary telescope". M-16 (the Eagle nebula in Serpens) is a "cluster of small stars, mingled with a faint light".

Today, of course, we know what diffuse nebulae like these are: immense condensations of gas and dust where new stars are being born. What we don't often realize is that we still see these objects exactly as Messier described them. Our minds, harking back to long exposure observatory photographs, interpret what we see into what is actually there. If we could train our minds to see exactly what Messier saw, we wouldn't be as disappointed in these objects' telescopic appearance as we often are.

Messier's Method

Charles Messier (1730-1817), compiler of the catalog of clusters and nebulae that bears his name, was actually not very interested in these objects; we might almost say he made his list in self-defense. Messier's main interest was comets, the nature of which was only beginning to be understood in the second half of the 18th century. Scientists knew that they approached the sun from the depths of space with a characteristic cloudy or "nebulous" appearance. Accurate measurements of position were required for orbital calculations — the more the better. Therefore, the earlier a comet was seen, the more positions could be obtained.

Messier discovered 15 new comets during a half century of observing, and carefully followed and plotted many others; he was one of the first to observe the initial predicted return of Halley's Comet in 1759. Not a theorist, he was interested solely in observational astronomy, leaving the explanations to others.

His reasons for compiling his list are best stated in his own words: "What caused me to undertake the catalog was the nebula I discovered above the southern horn of Taurus on Sept. 12, 1758, while observing the comet of that year .... This nebula had such a resemblance to a comet, in its form and brightness, that I endeavored to find others, so that astronomers would not confuse these same nebulae with comets just beginning to shine. I observed further with the proper refractors for the search of comets, and this is the purpose I had in forming the catalog."

Several points can be gleaned from this quotation. First, Messier's comet searching was done almost wholly with small refractors — which is why he could not resolve such objects as globular clusters, even near the edges. Also, his list is not as haphazard as some believe; occasionally Messier would look especially for nebulae and clusters, and his list is by no means composed solely of "accidental" discoveries. Otherwise, he would not have included Praesepe or the Pleiades, both of which had been known at least since the Greek era. For those objects that Messier knew had been previously observed, he scrupulously gave due credit. Many of the objects on the latter part of the list were discovered by Pierre Méchain, a younger colleague; there was no rivalry between Messier and Méchain, and they freely traded observations back and forth.

Toward the end of his life, Messier intended to revise and extend the catalog, listing the objects in order of right ascension. The upheaval of the French Revolution prevented this publication, however, and it apparently was destroyed.

The Orion nebula (M-42 and M-43) is the most famous member of this group, and most of the others — M-8, M-16, M-17 (the Omega nebula) and M-20 (the Trifid nebula) — are well-known. Only M-78 languishes in relative obscurity. M-16 and M-17 are the most distant of these objects (almost 5,900 light-years); by comparison, the nearest — M-42 — is only 1,500 light-years away.

Open Clusters

Messier was always on the lookout for comets, and most of the objects that eventually found their way onto his list had the nebulous appearance that a comet normally exhibits before it swings close to the sun and "grows" a tail. We might therefore wonder why Messier chose to include open clusters on his list — even those that could not possibly be mistaken for comets, like the Beehive (M-44) or the Pleiades (M-45).

For the answer, we must turn to Messier's own comments on the objects he observed. The Messier catalog is arranged, for the most part, in strict chronological order: Objects with high numbers were discovered or observed later than those earlier on the list. When we examine the first few open clusters in the catalog, we find that they *looked* nebulous to Messier under certain conditions. M-6 "appears as a nebulosity to the naked eye", as does M-7; M-11 "resembles a comet" in a small telescope, and M-18 "appears in the form of a nebula" with the same telescope. Not until Messier gets into the 20s does he begin to list open clusters on a regular basis; perhaps it was at this point that Messier decided he had a good thing going and determined to include open clusters in his list.

Whatever the reason, we are fortunate that Messier chose to catalog open clusters, for his list contains some of the most breathtaking in the heavens (although he inexplicably omitted the Double Cluster in Perseus).

Among such a varied collection, there is no "best" open cluster, and doubtless each observer will have his own favorite. Some will favor the wide clusters like the Pleiades, viewed with low power; others will prefer the tight, condensed M-11 in Scutum (the one that Messier thought looked like a comet). The three Auriga clusters — M-36, M-37 and M-38 — each have their own special attractions; their proximity in the sky provides a good basis for comparison. You might also want to compare M-46 and M-47 (close together in Puppis), or M-44 and M-67 (both in Cancer). M-44 — the well-known Beehive — is looser than M-67, and you can decide for yourself which type you prefer.

Most open clusters are nearer than their globular counterparts. The closest is M-45 (the Pleiades); at a distance of 410 light-years, the Pleiades are the nearest of all Messier objects. The farthest of the Messier open clusters is M-103 in Cassiopeia, 8,500 light-years away.

One of the open clusters on Messier's list is not a true cluster at all. M-24 is actually a detached starcloud of the Milky Way; it does, however, contain a true open cluster — NGC-6603 — which is small, faint and hard to spot. A six inch telescope is necessary to find it; the "true" M-24 is best seen with extremely low power, or even with the naked eye. Those who wish to substitute NGC-6603 for Messier's M-24 should be warned of its difficulty.

Globular Clusters

The Messier list abounds in globular clusters with 29, including most of the brightest ones visible to observers in the northern hemisphere. Messier's telescopes were ill-suited to any activity other than comet hunting, and his comment about most of the globular clusters in his list bears this out. Time and time again, Messier describes a globular cluster as a "nebula without star" — even M-13, the largest and brightest globular in the northern sky and one that is easily resolvable in small telescopes. Only M-4 and M-75 were described by Messier as being composed of small stars, and since M-75 is faint and difficult to resolve, Messier's comment is even more surprising. Messier, however, was not trying to resolve these objects as we do today, so we shouldn't be too hard on him for not doing so.

You'll immediately notice that, unlike open clusters which are distributed fairly evenly around the Milky Way, globular clusters are concentrated into a comparatively small area. Over half those on Messier's list are contained in three constellations: Ophiuchus, Scorpius and Sagittarius. All but one of the others can be found in the summer sky, not too far from this main concentration. The exception is M-79, located in the winter constellation Lepus.

This arrangement is not coincidental. A halo of globular clusters surrounds the nucleus of the Milky Way galaxy. Since this nucleus lies in the direction of Sagittarius, the globular clusters appear, from our viewpoint, to be packed tightly into this small area. Actually, many of them are as distant from the nucleus as they are from Earth; the nearest to the galactic center of Messier's globular clusters is M-62 in Ophiuchus.

As a rule, the globular clusters are much more distant from Earth than are open clusters. Of those on the Messier list, the nearest (M-4 in Scorpius) is about 7,500 light-years away, while the farthest (M-75 in Sagittarius) lies at a distance of 78,000 light-years.

M-13 in Hercules is certainly the best known of Messier's globular clusters; at magnitude 5.7, it is also the brightest. Other bright globulars include M-22 (5.9) in Sagittarius, which was the first globular cluster discovered; M-15 (6.0) in Pegasus, and M-92 (6.1), also in Hercules. The dimmest globular on Messier's list is M-72 in Aquarius, with a magnitude of only 9.8.

Some observers tend to dismiss globular clusters, after seeing a few of them, with the comment that "they all look alike". While they may present a smaller variety of appearances than open clusters, this statement is certainly untrue. Some have more obvious central condensations than others, and some cover a much larger area than others. Compare M-69, with hardly any central concentration, to M-15, with its exceptionally brilliant center and readily resolvable edges. Notice M-3 in Canes Venatici and M-62 — both "off-center" globulars of marked asymmetry. In short, there is enough variety among the Messier globular clusters to reward the patient observer again and again.

Galaxies

There are 37 galaxies on Messier's list — a larger number than in any other category of celestial objects. Messier, of course, didn't know about their true nature, and merely cataloged them — like globulars — as more "nebulae without stars". There are several galaxies not listed by Messier that are as bright or brighter than some of those on the list — a graphic illustration of Messier's method. Most of his galaxies were chanced upon during comet searches; even in the crowded galactic reaches of Virgo and Coma Berenices, Messier missed a few of the best.

What did Messier see in these objects? His description of M-31 is that it is "shaped like a spindle". He states that he "has examined it with different instruments and has not found a single star there". M-51 (the Whirlpool galaxy) is called a "very faint nebula without stars . . . it is double, each having a bright center . . . the two atmospheres touch each other. One is fainter than the other." M-81 is a "little oval", while M-82 is "faint and elongated".

Modern observers, reading these and other descriptions, and remaining blissfully unaware of the state of cosmology in the 18th century, are apt to snort in contempt at Messier's lack of knowledge. But the fact is that Messier has recorded remarkably accurate descriptions of these objects' appearance through the telescope. Again, we must remember that we view galaxies from a completely different perspective than Messier's. Two centuries from now, men may regard our knowledge with equal contempt.

It's true that small telescopes will show only as much as Messier saw, but we can appreciate more fully today exactly what it is we are seeing. This is nowhere more true than with the galaxies on Messier's list. We know, for instance, that M-31

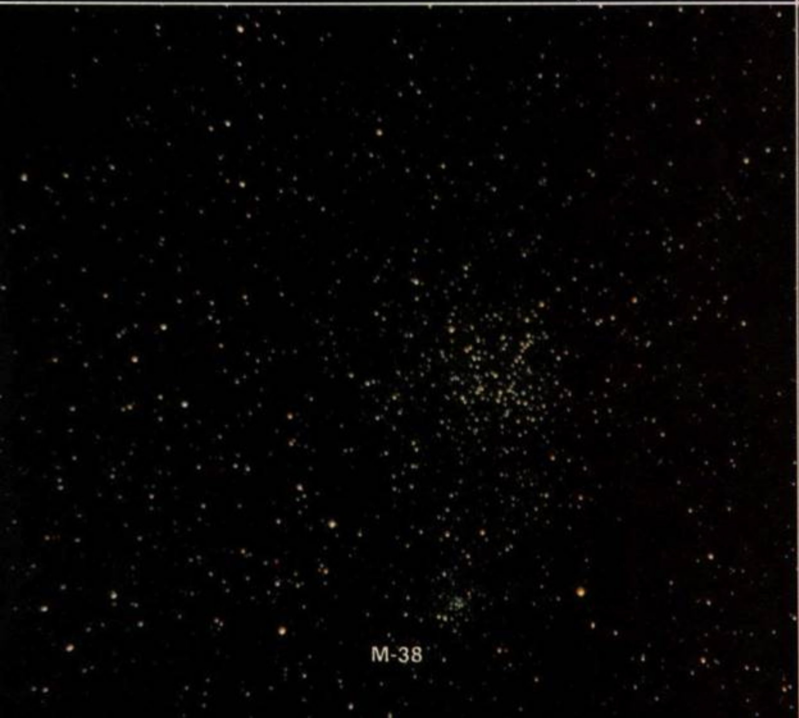
M-3, M-46 and M-47: Photographs by Brad Wallis. M-17, M-34, M-37, and M-38: Photographs by Robert Provin.

M-3

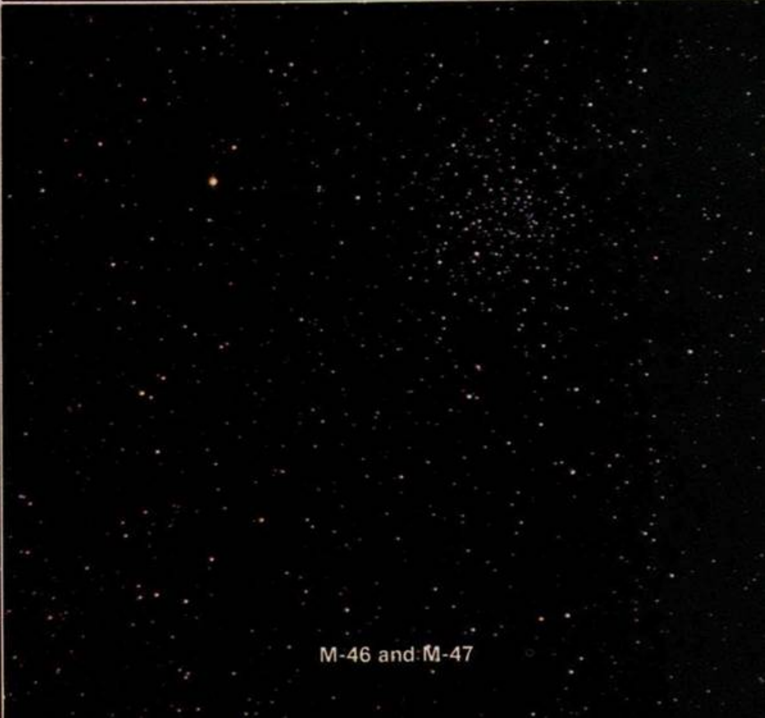
M-17

M-34

M-37



M-38



M-46 and M-47

M-64

M-65 and M-66

M-64: Photograph by Orien A. Ernest. M-65 and M-66: Photograph by Evered Kreimer.

— the spindle shaped nebula — is actually the nearest galaxy similar to our own Milky Way, lying at a distance of 2.2 million light-years. In a clear sky, through telescopes of eight inches aperture or larger, M-31 is certainly one of the most impressive objects in the heavens.

The smallest and least massive of the Messier galaxies is M-32, one of the companions to M-31. In comparison to M-31's 320 billion solar masses, M-32 contains about three billion. Second smallest is M-33, which covers a large area in the telescope because of its relative nearness, but contains only eight billion solar masses. M-31, M-32 and M-33 are all members of the Local Group of galaxies — a cluster that includes the Milky Way.

The most massive of all the Messier galaxies are the ellipticals M-49 and M-60, each of which holds about one trillion solar masses, and M-104 (the Sombrero galaxy) which contains about 1.3 trillion.

The most distant Messier galaxy is M-77 in Cetus, about 52 million light-years away. The nearest, aside from the members of the Local Group, are M-81, M-82 and M-83; all are about 8.5 million light-years away.

The brightest Messier galaxy is, of course, M-31, visible to the naked eye at magnitude 4.8. M-64, the Blackeye galaxy in Coma Berenices, is magnitude 6.6, and M-33 is 6.7. The faintest Messier galaxy is M-98 in Coma Berenices, which has a magnitude of only 10.7. Although it is closer to us than the many members of the Coma-Virgo galaxy cluster, it is not as bright as the most luminous members of that group.

Just as the globular clusters seem to be concentrated in the summer Milky Way, so are the galaxies apparently condensed into the spring sky. Only five of Messier's group are not visible during spring. Here, again, we are witnessing an illusion; because the Milky Way blocks our view of the space behind it, we cannot see into intergalactic space except when we look away from it. The Milky Way lies on the horizon during the spring, so its dust does not obscure the galaxies behind it; therefore we see more. The other five are visible in the fall — again when a large portion of the sky is unblocked by the Milky Way.

Crab Nebula

It is perhaps fortunate that the unique object known as the Crab nebula, which falls into none of these categories, is numbered one. Messier described it as "a whitish light, elongated like the flame of a candle". Today, of course, we know that M-1 is the remains of the supernova of 1054. It is one of the most intensely studied objects in the heavens, and

Additional Messier Objects

Messier No.	NGC No.	R.A.	Dec.	Type	Size	Mag.	Constellation
104	4594	12^h37^m	-11°21'	Sp	6'x2.5'	8.7	Virgo
105	3379	10^h45^m	+12°51'	El	2.2'x2'	9.2	Leo
106	4258	12^h16^m	+47°35'	Sp	19.5'x7'	8.9	Canes Venatici
107	6171	16^h29^m	-12°57'	GC	8'	9.0	Ophiuchus
108	3556	11^h08^m	+55°57'	Sp	7.7'x1.3'	10.7	Ursa Major
109	3992	11^h55^m	+53°39'	Sp	6.2'x3.5'	10.8	Ursa Major

GC = Globular Cluster El = Elliptical Galaxy Sp = Spiral Galaxy

contains the first discovered pulsar. Notwithstanding, M-1 is quite difficult to see, and you'll probably have trouble picking it up in a small instrument.

Missing Objects

Four of the objects on Messier's original list of 103 items either are not true clusters or nebulae, or are missing entirely. To help observers avoid confusion, and to explain those dashes or blank spots in most printed lists, we'll run through these items briefly.

M-40 is a double star in Ursa Major known by the name of Winnecke 4. Why Messier included it is a mystery, since even he admitted that he saw only two stars here. The object had appeared on a previous list of nebulous items compiled by an earlier observer — most of which simply don't exist. M-73 is an asterism of four stars in Aquarius, not a true cluster. It is quite inconspicuous — no more prominent than any other chance arrangement of stars.

M-91 and M-102 are the missing objects. Nothing can be seen in the positions Messier reported for these numbers. M-91 is described as "above number 90", but the object which most reasonably fills this requirement is NGC-4571 — and this galaxy is dimmer than any other galaxy on Messier's list; it could be that M-91 was actually an unrecognized second observation of M-58. M-102 was reported to Messier by his colleague Pierre Méchain, and was included in Messier's published list at the last minute before Messier had a chance to observe the reported position himself. Méchain later admitted that M-102 was probably a duplicate observation of M-101; some lists award the M-102 title to NGC-5866, a galaxy in Draco.

M-47 and M-48, for years regarded as other missing objects, have been convincingly identified as, respectively, NGC-2422 (an open cluster in Puppis) and NGC-2548 (an open cluster in Hydra).

Additional Objects

Although Messier intended to continue his list beyond the 103 items he published, age and failing health prevented him from doing so, and the "official" list remains at 103. There have been recent attempts to extend the Messier list past this number, to include items that Messier did not publish but undeniably knew about (as evidenced by letters or private notes).

These additional items have gained wide (although not universal) acceptance as genuine Messier objects, and the catalog now goes as far as 109. Not yet included on every published list, the extra items are listed in the table above.

Needless to say, 109 numbers don't include everything. Messier left out quite a few bright objects; the most notable omission is one we've mentioned earlier — the Double Cluster in Perseus. Messier also did not list the Rosette nebula in Monoceros, the North America and Veil nebulae in Cygnus, the Helix nebula in Aquarius and NGC-6543 in Draco (both planetary nebulae), plus a large number of bright globular clusters and galaxies. In addition, working as he was from the high latitude of Paris, Messier had no access to the southern sky and the splendid objects there.

Even so, astrophotographers have, in the Messier list, a wealth of varied beauty available to their cameras; unfortunately, the same few Messier objects seem to get photographed over and over. Diffuse nebulae are the favorite subjects; there may be more photos of M-42 in existence than all other subjects combined. Among globular clusters, M-13 is popular, but why doesn't anyone photograph M-71 — an object in Sagitta so peculiar that it could be either a very loose globular or a very compact open cluster? Good photographs of open clusters besides the Pleiades, the Beehive and M-35 are rare. Everyone wants a picture of M-31 because it's large and bright, but other galaxies like M-74, M-77, M-83 and M-101 — all beautiful spirals — are almost completely ignored.

From today's light polluted cities, the objects of the Messier catalog are undoubtedly less impressive than they were to Messier. But in a dark country sky, even a small instrument will reveal the beauty and grandeur of many objects on the Messier list, and larger telescopes will provide views that are simply indescribable. Messier provided a more valuable list than he knew. He may, perhaps, have preferred to be remembered by a huge, bright "comet Messier", but his catalog of clusters, nebulae and galaxies provides a firm, much less ephemeral tribute to his name.

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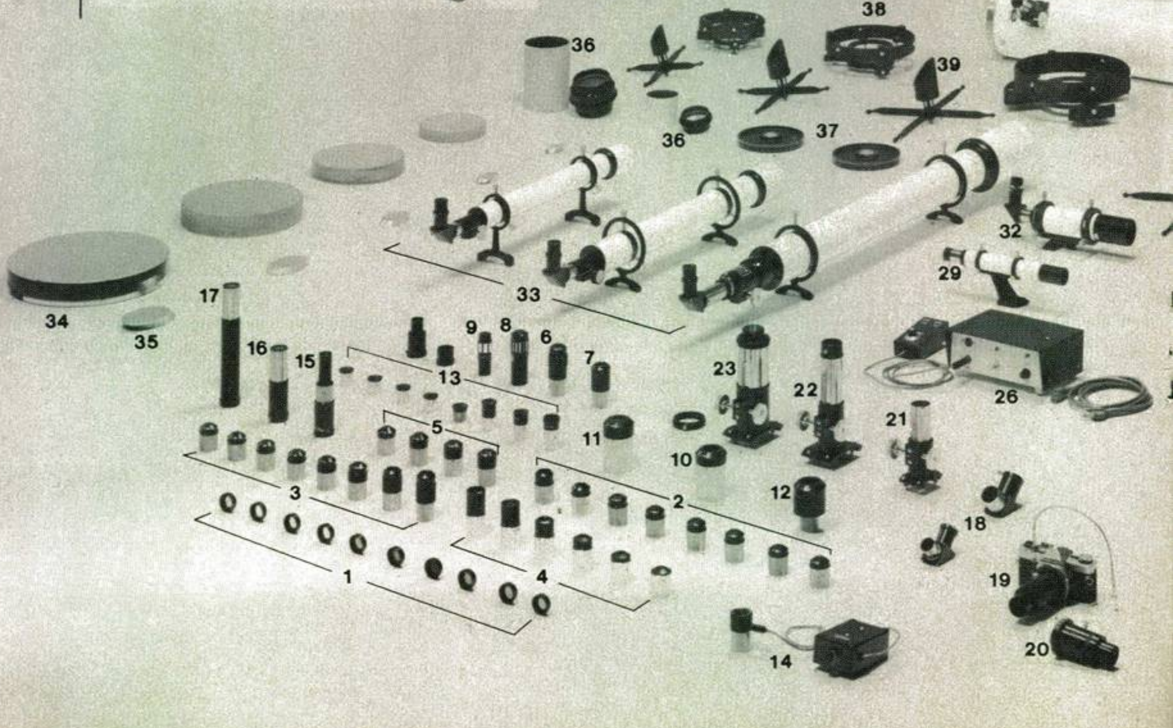

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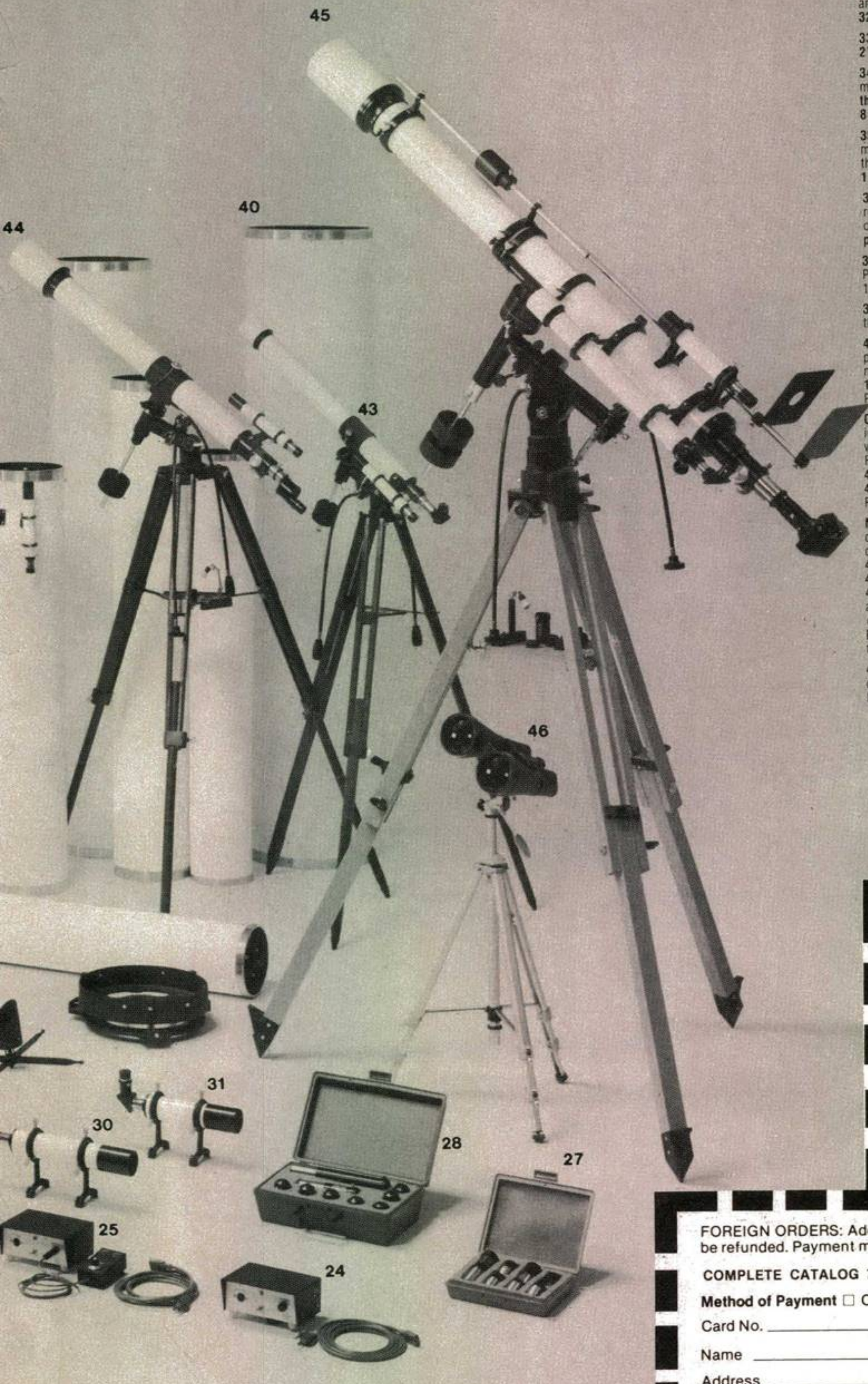

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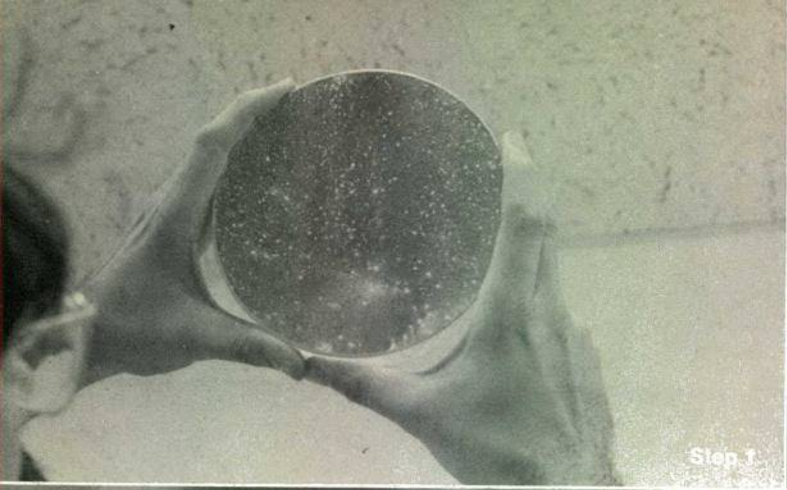

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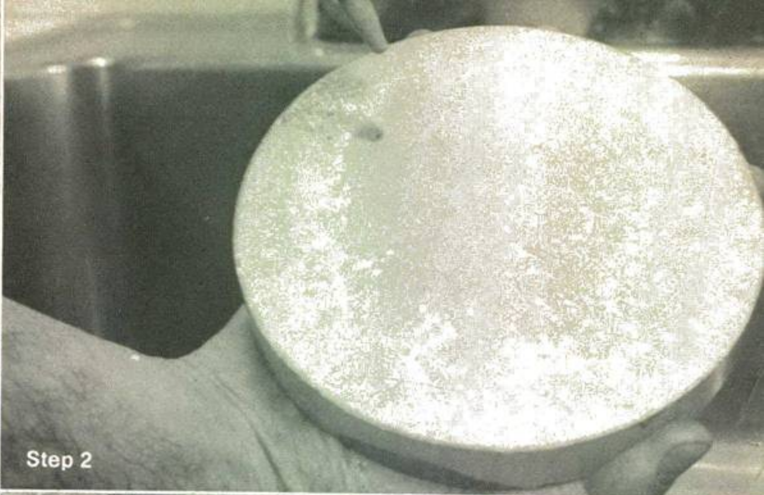

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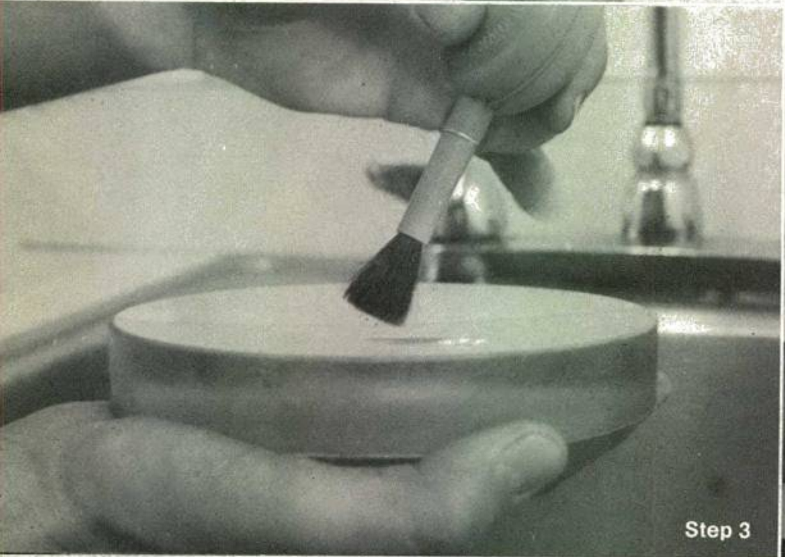

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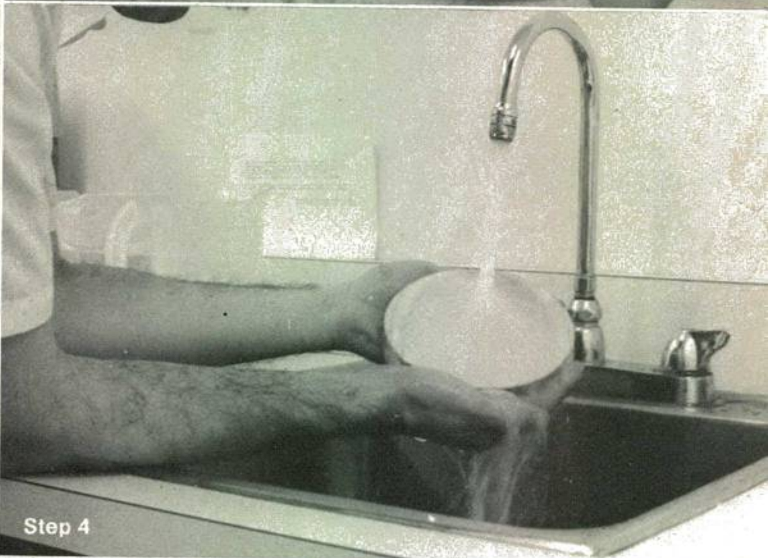

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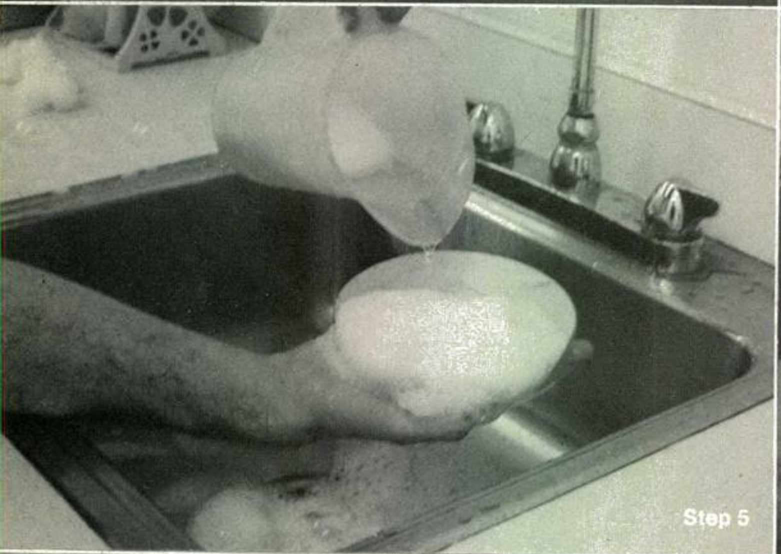

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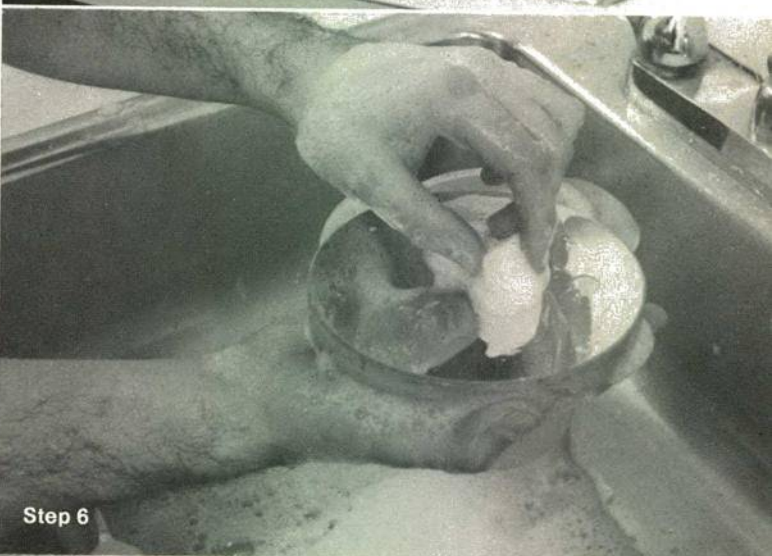

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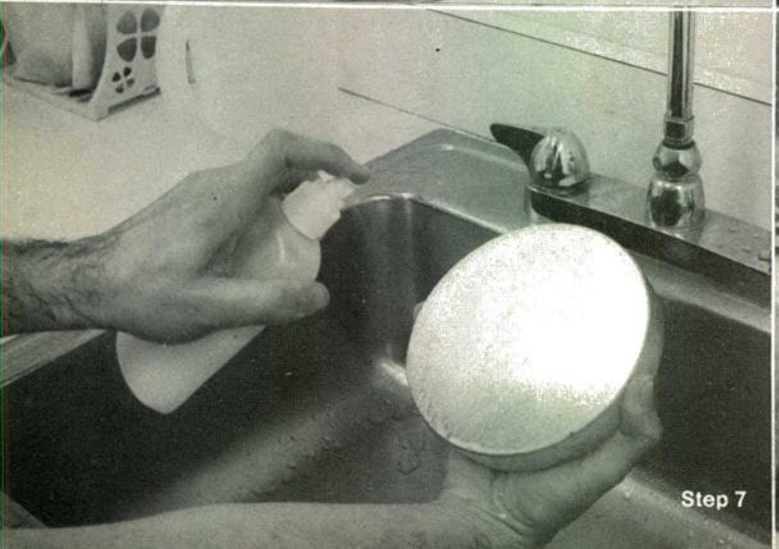

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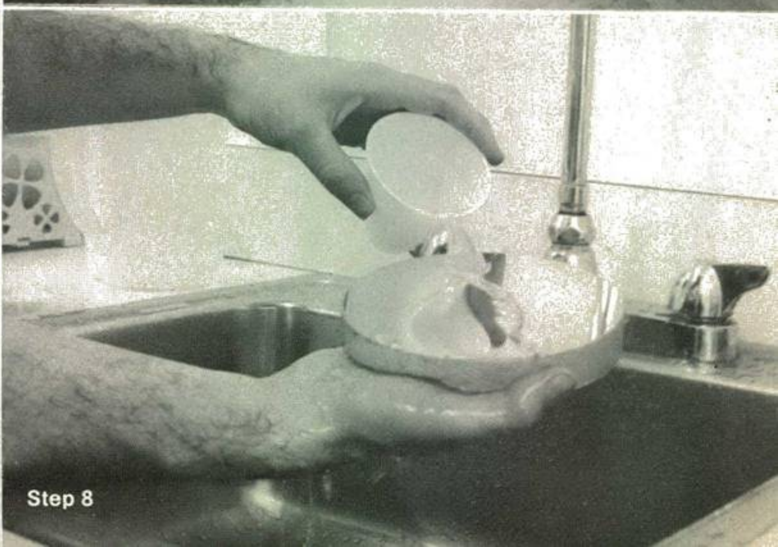

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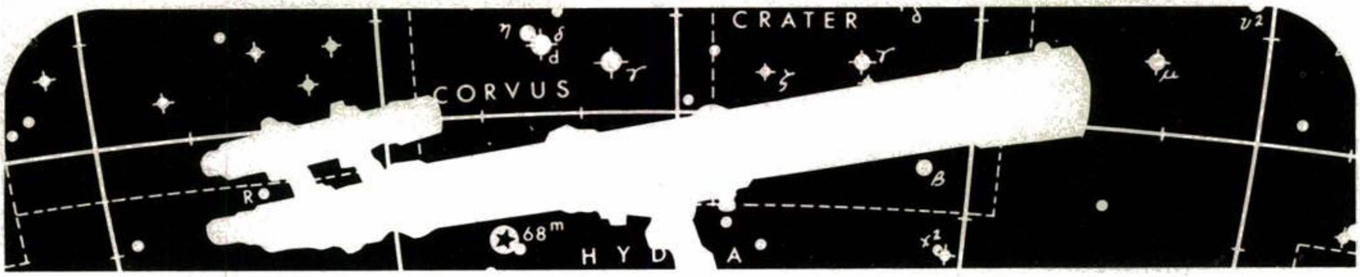

Cleaning Your Telescope Mirror

by
Richard Berry

Clean telescope optics transmit more light, give better, crisper images, and are more likely to provide satisfactory telescope performance. Of course, you shouldn't let them get dirty in the first place. A close-fitting plastic cap (a shower cap works well) over both ends of the tube keeps out dust when the telescope is not in use, but sooner or later you'll look at your mirror or lens and notice spots and dust. A bit of dust does very little harm to the image, but if you can see it from the end of the tube, it's time for a wash. A word of warning, however; Too many washings can damage the mirror coating. Don't wash the optics if they don't need it.

Washing a mirror is simple: It's dunked in warm soapy water, the dirt comes off, it's rinsed clean, and then dried. But remember that you're washing a surface that can be scratched very easily. If there's gritty or scratchy dirt on the surface, you must remove it first. At no time can you scrub the mirror surface as that's a sure way to scratch or sleek it. Finally, you'll have to take extra care in drying the mirror to prohibit marring the mirror surface by tap water deposits.

There are lots of recommended procedures for washing telescope mirrors, and it doesn't essentially matter how you do it as long as you get good results. Following is a method that works well.

1) Remove the mirror from its cell. Resist the temptation to wipe the biggest piece of dirt away immediately; to do so is to invite a big scratch. Hold the mirror up to a light and look through it. A good coating should be opaque. If you can see through it, or if it's full of holes, the mirror should be re-aluminized. But cleaning won't hurt.

2) Gently blow off any dirt that will come off. If your dirt consists mainly of lint, you may have no need to clean any further. Photo stores sell cans of compressed gas for cleaning film that can be used for mirror cleaning too.

3) With a very soft camel's hair brush, about 1/2 inch wide, brush the worst of the dirt and dust off the mirror. Use short, exceedingly light strokes — don't wipe right across the whole width of the mirror. If a sharp bit of gravel were to stick to the brush, you'd drag it right across the whole remaining width of the surface and probably leave an ugly mark. After most of the dust is gone, you can try a bit harder on some that won't come off.

4) Using room temperature water, rinse off the surface, letting the water pressure remove everything that it can. Gently warm the mirror up by slowly increasing temperature until it's lukewarm. Sudden changes in water temperature must be avoided. You can see the dirty areas on the surface by the disturbed flow of water over them. The water rinse removes water soluble dirt.

5) Pour a cup of warm, soapy water on the mirror. Let it soak a few moments, and then rinse it off. Soapy water will loosen oily and greasy kinds of dirt.

6) Using a cotton wad with no pressure at all, wipe the whole surface of the mirror with short circular strokes. If you feel a sudden drag or pull, stop immediately. Wash it again with soapy water. At the end of this step, no dirt should be left on the surface.

7) If the surface has light colored stains, spray the surface with a good ammonia based window cleaner; the stains will usually come off. Don't scrub or buff the surface. As a last resort, dilute nitric acid (no scrubbing with acid either!) will usually take them off.

8) Thoroughly rinse the mirror in tap water, and then rinse it at least twice in distilled water. (You can buy distilled water in the supermarket in gallon bottles, but it takes very little water to rinse a mirror.) Then leave the mirror standing on edge (a kitchen drainer is quite safe) until dry. Resist the tempation to speed up the drying.

The same method can be used to clean a refractor objective, but if possible, avoid removing the objective from the telescope. If simple blowing and brushing does not remove the dust, you'll have to remove the objective, wash it carefully, and reassemble it. Preventive medicine is best: Don't let the objective get dirty in the first place!

Aligning Your Finder

by
Mary Jane Lamers

One of the most important accessories on the observer's telescope is a miniature version of the larger instrument called the finderscope. Since this is mounted on the side of the main scope, it is vulnerable to bumps and bruises that can easily put it out of alignment.

Having it misaligned is bad enough, but it's even worse because you usually don't discover the problem until you try to use the finder. Instead of jiggling the finderscope back and forth in the dark in an attempt to get it to work, take time out some afternoon when you have lots of light available. Objects are much easier to see in daylight and less confusing than stars in the night sky that all tend to look alike.

The first step in aligning your system is to set the finder roughly parallel to the main telescope. This way the finder will be parallel to the optical axis of the telescope.

Next, sight the telescope on a distant vertical object — something like a telephone pole is a good choice. Some recognizable point on the pole should be placed exactly in the center of the telescope's field. Now carefully lock the main telescope into position to prevent any movement. After securing it, make sure that the object is still dead center.

Look into your finderscope. If the object you've sighted on isn't exactly in the center of the reticle (crosshairs), you'll know why you've had trouble finding things. Carefully loosen the screws in one of the mounting rings and center the telephone pole on the vertical axis of the crosshairs. It's important to have a light touch in doing this; any jarring motions may throw the object out of the center of the main telescope's field. Usually, finders are easily aligned with adjustable screws that are simple to manipulate. After your finderscope is secured, check the main instrument to be sure the object is still exactly centered.

So there you are — a few careful adjustments during the day can save you considerable frustration at night, leaving you with more time for observing.

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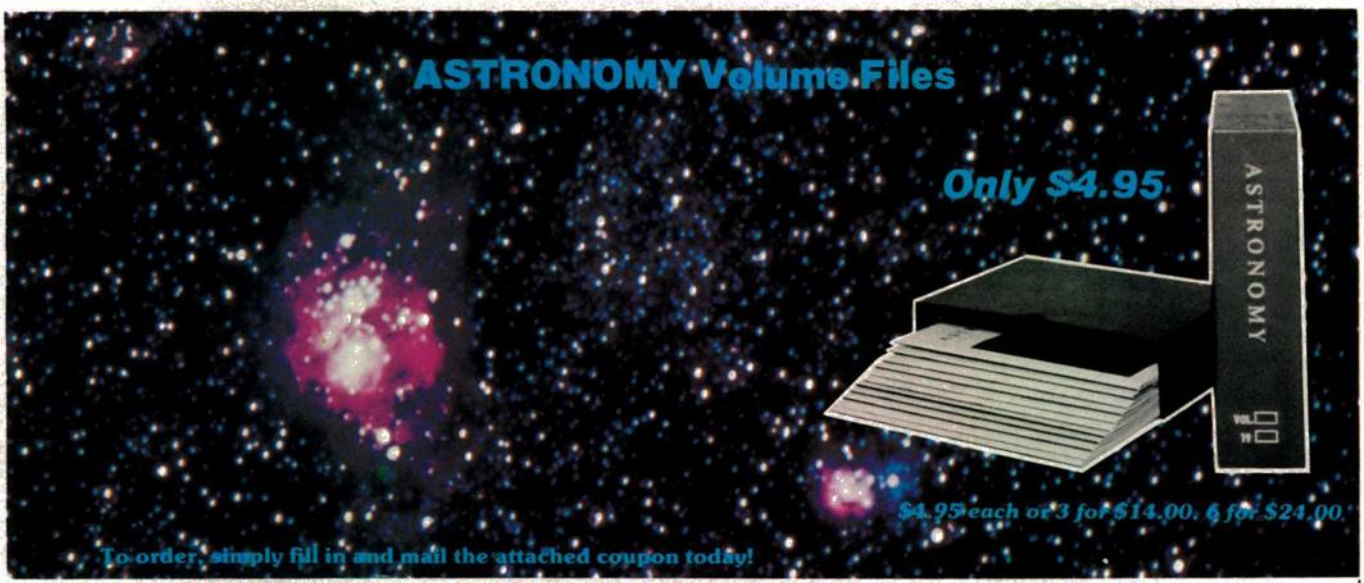
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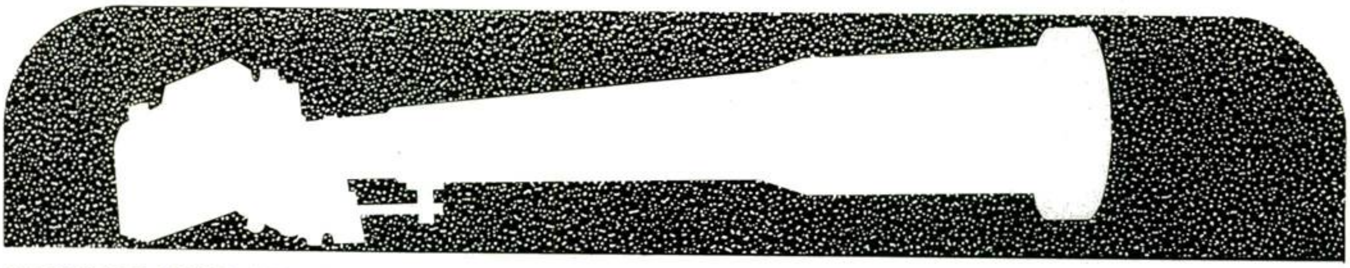


Printing Your Astrophotographs

Part 1: Basic Printmaking

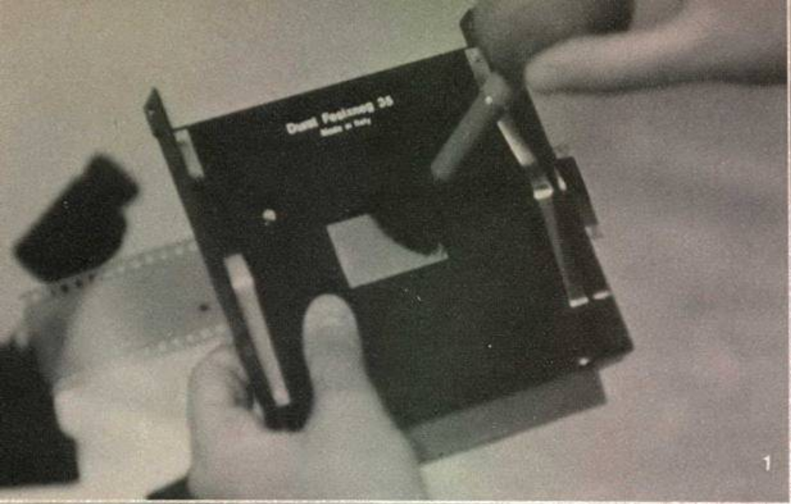
by
David Hudgins

Bringing the tiny images from your negatives to life in enlargements is one of the more enjoyable aspects of astrophotography. It's easy and relatively inexpensive for anyone to set up a home darkroom and make prints that are better than those done by commercial processors. By doing your own printing, you can provide special care and use techniques required to reproduce the faint images typical of most astronegatives. Equipping a home darkroom does require some investment — about $100 to $150 if the equipment is purchased new — but the rewards are correspondingly great.

Your darkroom can be as simple or extravagant as your interest, pocketbook, and available space allow. A permanent darkroom with all the frills can be convenient, but a temporary setup in the kitchen, bathroom or basement is more than adequate. The important things are: 1) to have a small undisturbed area that you can darken completely (a blanket over a window is often sufficient), and 2) a countertop or space for a card table where you can set up your equipment for a few hours. Running water is handy, but a water-filled bucket is fine for holding prints until you can get them to the bathtub or sink for final washing. (For a list of equipment needed, see "Setting Up An Astrodarkroom", June 1976.)

Black and white enlargements basically involve projecting the image of your negative onto a sheet of photographic paper that is coated with a light-

Printing astrophotos can be done on any waterproof counter surface that you can darken. The basic steps in making a print are: 1) cleaning dust from the negative; 2) focusing the enlarger, using a "grain focuser"; 3) placing a sheet of photographic paper on the enlarging easel; 4) making the exposure on the paper; 5) sliding the paper into the developer tray and 6) removing it *after it has developed*; 7) washing the paper after stopping and fixing the print, and 8) drying the paper (shown here on towels). Photographs by David Hudgins.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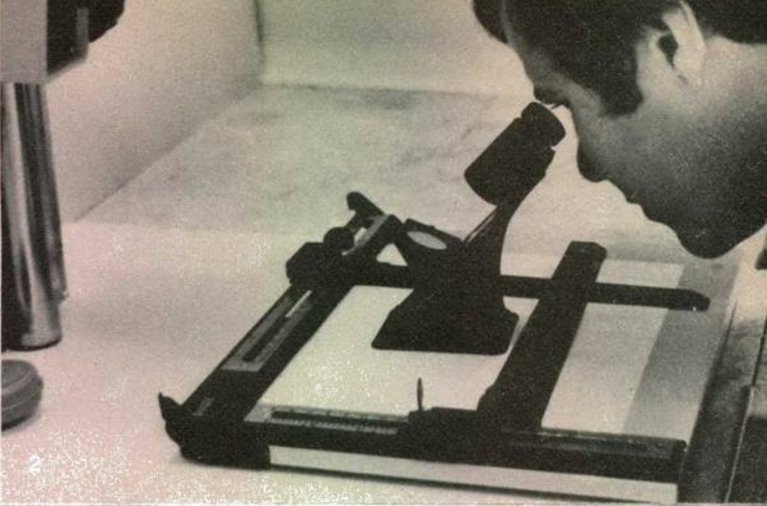

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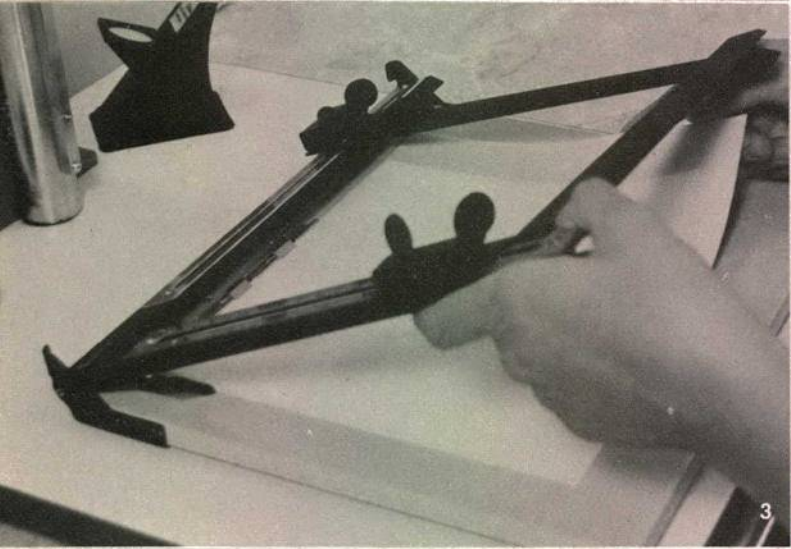

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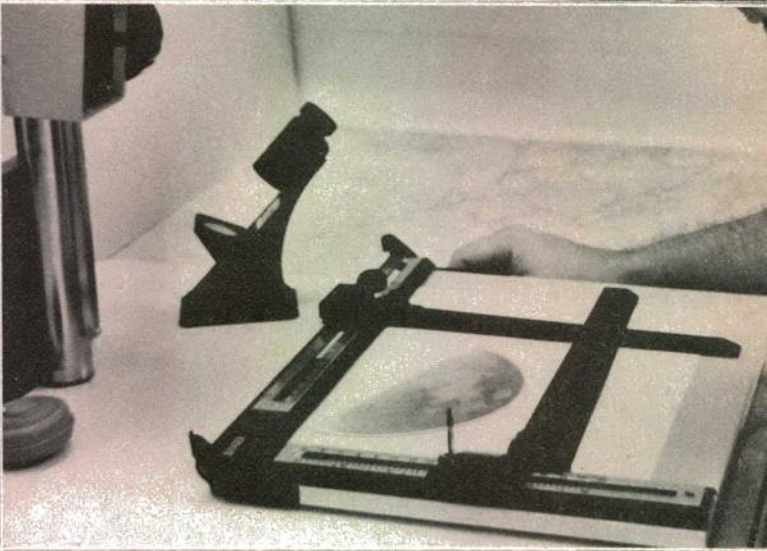

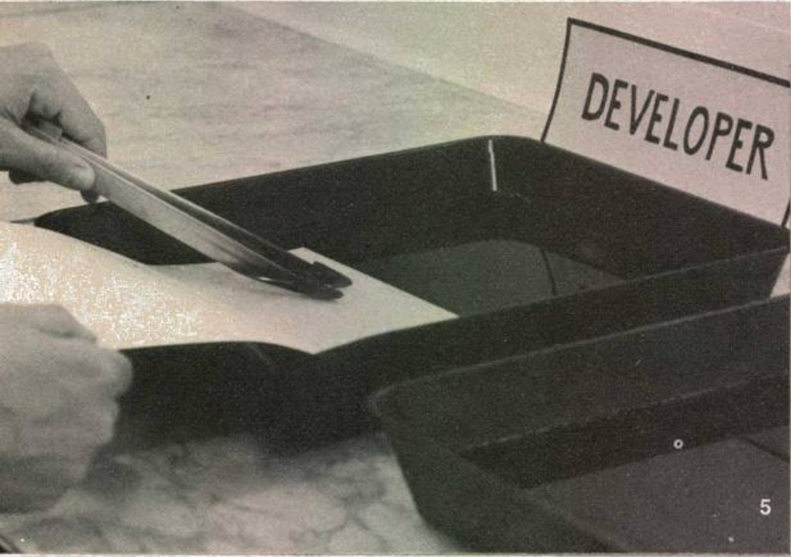

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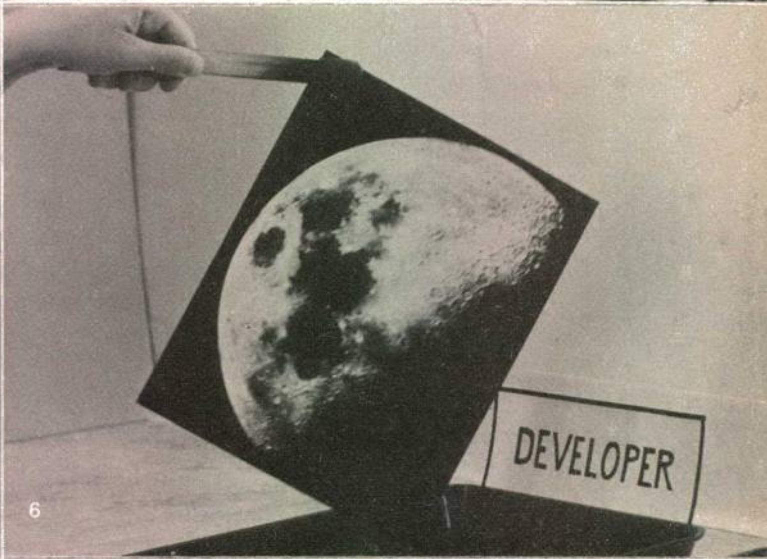

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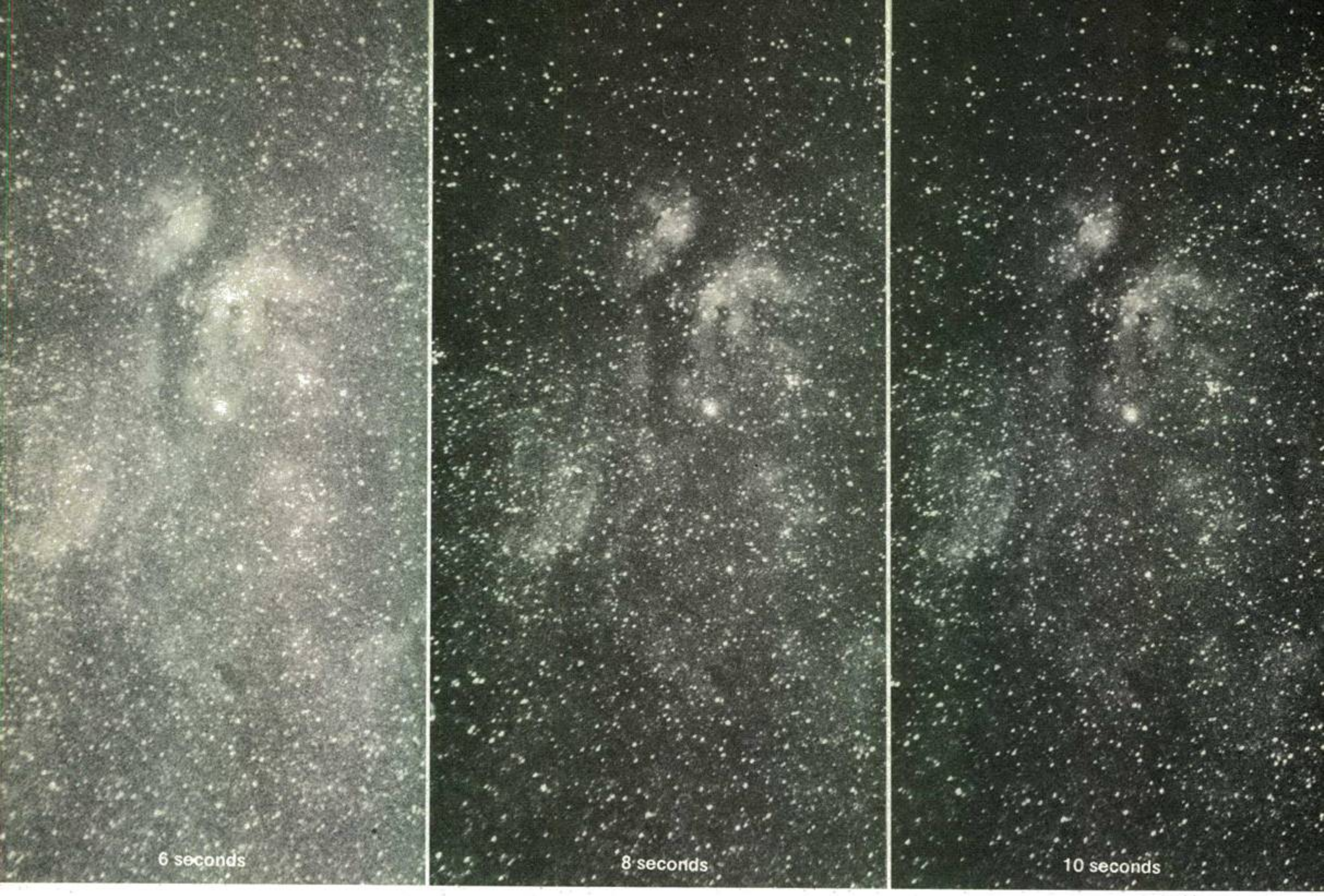

6 seconds

8 seconds

10 seconds

These prints made from the same negative (showing the red nebula near Gamma Cygni) illustrate the changes that occur when you increase print exposure. For maximum detail in the nebula, you would find an exposure between six and eight seconds best — seven might be a good compromise. For maximum impact on display, a darker sky (but not black) is desirable — perhaps 14 seconds is best. Longer exposures obscure the nebula. Photographs by David Hudgins.

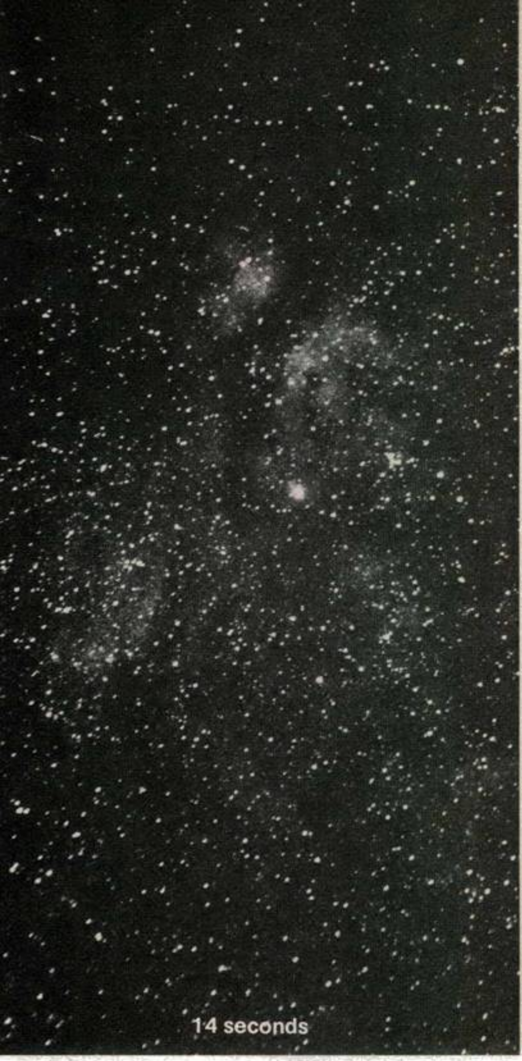
sensitive emulsion. The paper sheet is then placed in a *developer* solution that makes the image visible, and then in a very dilute acid *stop bath* to arrest further development. A final solution, called the *fixer*, makes the paper insensitive to further exposures to light. Finally, the paper is washed to rid it of the chemicals, and dried. A darkroom is nothing but a place where you can carry out this procedure using specialized — though readily available — equipment and materials.

The single most important piece of equipment in the printing operation is the enlarger. Although they look complicated, enlargers are simple devices consisting of a lamp with a lens system to condense the light, a holder for the negative, and a lens to project the image. The enlarger "head" has a mechanism that lets you raise or lower it so that you can adjust the image from wallet size up to about 11 x 14 inches.

The enlarger will probably be the most expensive single item in your darkroom. You might consider a used enlarger if you are on a tight budget; an older but still serviceable model can be purchased for $25 to $50. A new enlarger of reasonably good quality will cost from $75 to $125; Bogen, Durst and Vivitar are among several manufacturers of good, low priced enlargers. The price will frequently include an inexpensive lens which, although not the best, is quite suitable to start with (you can always buy a better lens later). In selecting the focal length of the enlarging lens, you'll need a 50mm lens to produce a suitably large image size for 35mm negatives, and a 75mm focal length lens for 2-1/4 x 2-1/4 films.

Other important items you'll need are three 11 x 14 inch trays, print tongs, an adjustable easel, red or amber safelight, a lens cleaning brush or aerosol can of compressed air, and a darkroom thermometer. Discount stores are often good sources for three quart-size plastic bottles, a kitchen graduate, sponges, clock or timer with visible sweep hand, and a magnifying glass for sharp focusing. Assuming you already have a suitable clock, all these items will cost about $35. As your interest and enjoyment of darkroom work increases, you may want to buy a "grain focuser", paper cutter and print washer.

Selecting chemicals for developing prints is even easier than for film. Beginners and pros alike generally use the same three Kodak products — Dektol developer, Indicator Stop Bath, and Rapid



14 seconds

18 seconds

24 seconds

Fixer. These chemicals can be used for all enlarging papers, although plain water works just as well as an acid stop bath for RC papers (explained below). Carefully mix the concentrated liquids and powders with water according to the instructions and store them in labeled plastic bottles. Be sure to keep all measuring cups, stirring rods and mixing containers clean to avoid contamination of the chemicals.

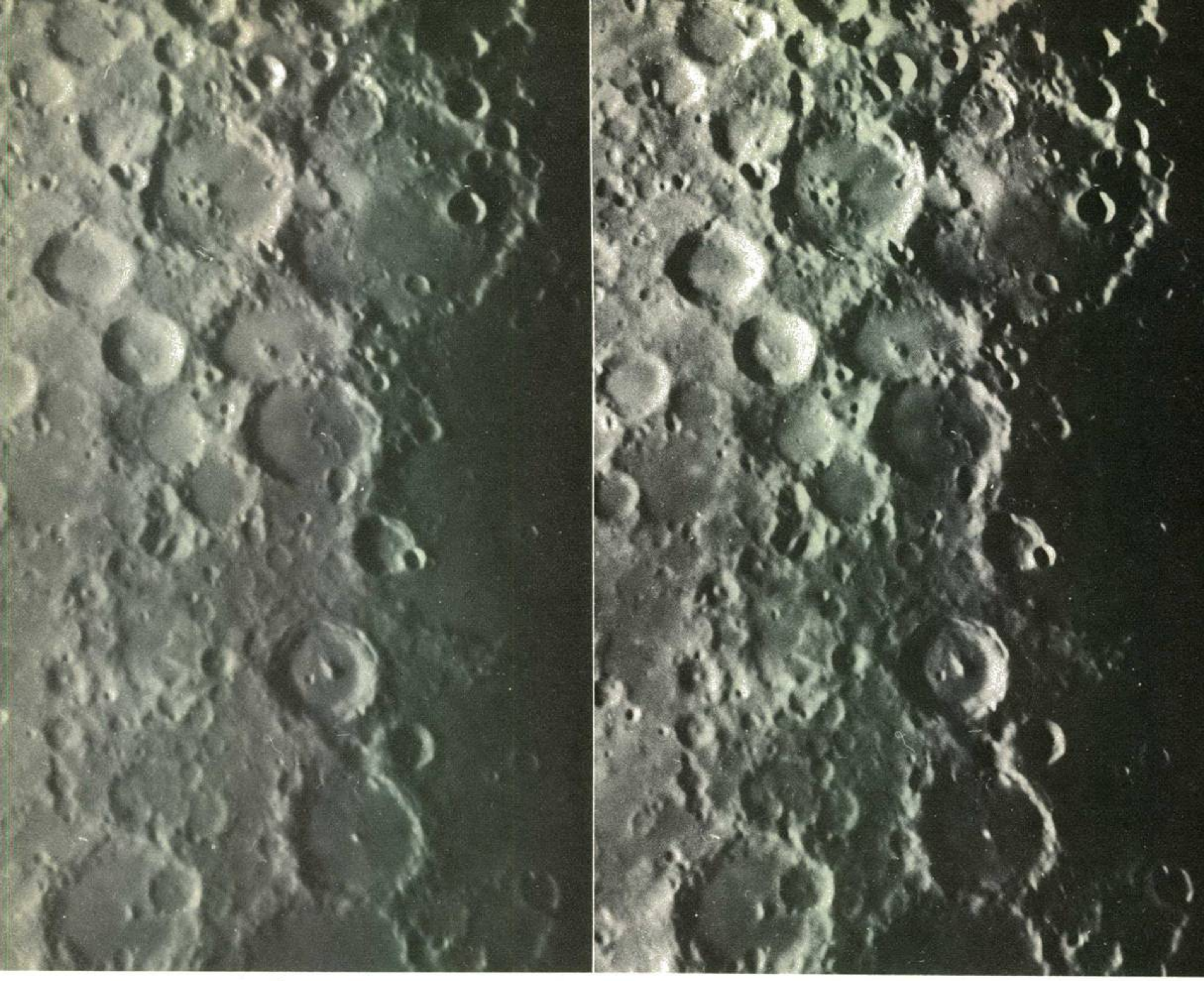
Dektol developer is normally used diluted with water — one part Dektol to two parts water. Many astrophotographers prefer to use a stronger mix to increase print contrast. Both Dektol and Rapid Fixer have shelf lives of several months, and will process 25 (approximately) 8 x 10 inch prints per quart of stock solution before they should be replaced. Kodak Indicator Stop Bath has an almost indefinite shelf life; the working solution is good until its normal yellow color turns blue.

Of the many variables in the printing operation that influence the final print, probably the most important is the choice of a printing paper. Printing papers are basically like film; light-sensitive silver halides are suspended in a gel or emulsion coated on a high quality paper backing. Compared to films, however, printing papers are much less sensitive to light — particularly red light. They are made this way so that you can handle them easily in the darkroom by the dim illumination of a red or orange safelight.

Printing papers are available in a wide variety of surface textures, image tones, weights, and contrast levels. With such a variety, how do you know which is best? The requirements for astrophotos are specific, so it's easy to learn what to look for.

Good astrophotos have brilliant highlights, rich blacks, fine detail and maximum tonal range. Only glossy surface papers produce the clarity required for astrophotography; matte, silk or linen finishes will cause a loss of detail in your final print because of their comparatively rough surfaces. Glossy surfaces are produced on conventional printing papers by squeegeeing a wet print face down on a polished metal suface, and then allowing it to dry (the process is called ferrotyping). An easier way to get a perfect glossy surface is to use one of the new resin-coated (Kodak's "RC" trademark) printing papers.

RC papers are coated on both sides with a water-resistant plastic that prevents the various processing solutions from being taken up by the paper except at the edges. The emulsion is applied over the plastic so the developer and fixer can reach it. Since chemicals cannot soak into the paper, fixing, washing and drying are much faster than with conventional papers; in addition, the shiny surface is created in the factory, thus eliminating the tricky ferrotyping operation. These time-saving benefits



Low contrast and high contrast prints from the same negative show the great control your choice of contrast grade gives you when you make your own prints. This moonscape was printed on normal contrast grade 2 paper at left; at right it's on high contrast grade 6 paper. While both renditions have their merits, one is too flat and the other too "contrasty". In this case an intermediate grade 4 paper would have produced the best print, showing detail in the terminator shadows as well as the brightest crater rims.

give you more time for the experimentation required to produce the highest quality astroprints.

Look for the same qualities in RC papers that you would seek in conventional papers. The label on the package should specify image tones that are neutral black and white. Cream colored papers used in portrait work are not suitable for photos of stars and planets.

Next, check the label for the paper weight, usually specified as either single-weight or double-weight. Double-weight paper is heavier and costs more, but is much easier to work with because it resists bending during processing. (Due to the extra stiffness provided by the plastic coating, some RC papers are available in only a medium-weight grade.) The last thing to look for is the contrast grade, usually specified as a number from 1 to 5 (the #1 produces very low contrast prints, while #5 yields prints with high contrast). Instead of numbers, some manufacturers use letters to indicate contrast. For general astroprinting, a moderately hard paper such as a #3 is most widely used.

In recent years, variable contrast papers have become popular. These papers will yield different levels of contrast, depending on which of several filters is used under the lens of your enlarger. This means that you only need one box of paper in your darkroom instead of three or four of various contrast grades. While handy, variable contrast papers cannot produce the extreme contrast levels of #5 papers.

The first rule in printing astrophotos is cleanliness! Fingerprints, dust and scratches are painfully obvious when enlarged against a dark sky background. Every printing session should start with a cleanliness check: brushing the enlarger lens, periodic sponging of the inside of the enlarger, cleaning of condenser lenses, wiping tabletops and easel, making sure clean cloth or paper towels are handy, and finally a careful washing of your own hands.

Pour the developer, stop bath and fixer into their trays, and then check their temperatures. Solution temperatures are not as critical in processing prints as they are for films, but developing times are most controllable in the range of 65 to 78 degrees Fahrenheit. Use a plastic sandwich bag partially filled with either hot water or ice cubes to bring your solutions to this temperature range. Now you are ready to start.

First, carefully examine and clean the negative. Use an antistatic cloth, aerosol can of compressed air, or a soft lens-cleaning brush to clean both sides of the negative. Put the negative in the carrier, brush everything off once again, and place the carrier in the enlarger. Turn off the room lights and give your eyes a few moments to adjust to the dim illumination of the safelights. Turn on the enlarger lamp, open your enlarging lens to give the brightest image, and select the print size you want by moving the enlarger up or down (relative to the easel placed beneath it). If you use an adjustable easel, you can set the blades to make a 1/4 inch white border around the print. Since most enlarging lenses are not very sharp when wide open, you should close yours down about two f/stops. Carefully focus the image on the back of a piece of processed enlarging paper placed in the easel; either a grain focuser or a magnifying glass will help you get the sharpest image possible.

To find the best exposure time, first make a test strip using a piece of enlarging paper about two inches wide and five inches long. For photos of stars and nebulae, place the strip so that it will be exposed to areas of dark sky; later you can judge the proper exposure based on the time required to darken the sky background to the optimum darkness.

By watching the second hand on a clock or listening to the ticks, expose the entire strip for five seconds. Next, using a piece of cardboard, cover a portion of the strip about 3/4 inch wide while giving additional exposures of 5, 10, 15, 20 and 25 seconds. In this way, you'll get a series of progressively darker bands corresponding to the various total exposures.

After exposing the paper, slide it smoothly into the developer so that the emulsion is rapidly and totally covered by the solution. Rock the tray gently to keep fresh developer washing over the paper. Dim images will begin to appear in about 20 seconds. Total development time depends on the kind of enlarging paper you are using; conventional papers should be developed for 90 to 120 seconds, while RC papers require about 60 seconds (check instructions that come with the paper). Watch your clock carefully, and then use tongs to lift the paper from the developer at the correct time. Allow the paper to drain over the tray for a few seconds and then slide it into the stop bath, being careful not to let the developer tongs touch the stop bath solution since this could contaminate the developer.

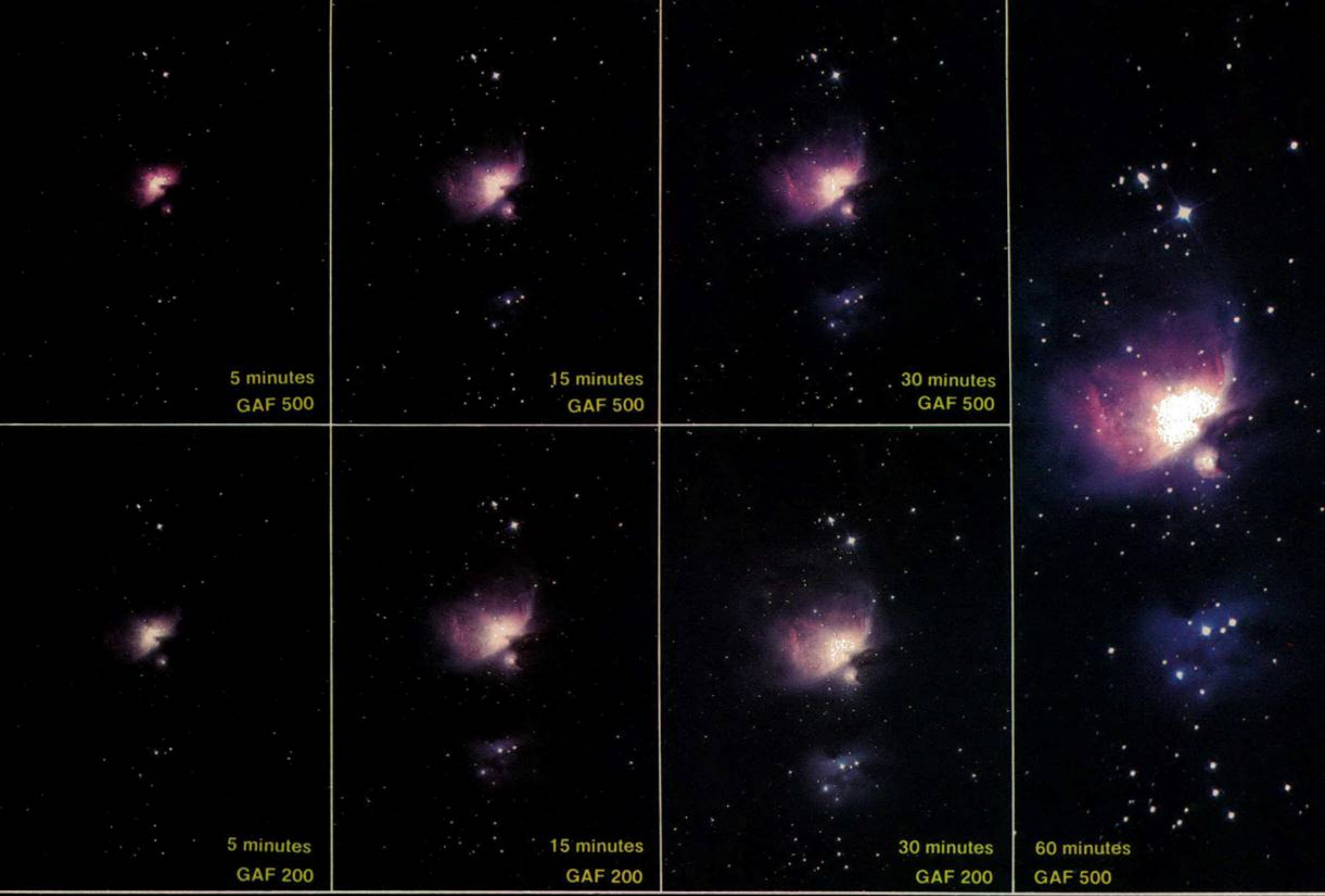
After 30 seconds in the stop bath, your test strip goes into the fixer. Proper fixing takes about five minutes for RC papers or 10 minutes for conventional papers, but you don't have to wait that long for a test strip; you can turn the room lights on after about 60 seconds. A word of caution: Don't try to "read" a test strip under the safelight; you must see it under bright room lighting to judge its darkness properly.

Your test strip for star photos will show a series of progressively darker bands corresponding to exposures of 5, 10, 15, 20, 25 and 30 seconds. Examine the background density carefully, looking for the exposure that produces a dark, but not jet black, background. The night sky never looks totally black through the telescope, so there is reason to portray it that way in your prints. More importantly, the slightly lighter background always reveals more stars and nebulosity than an absolutely black one can. Since planet images are usually too small to make a test strip like the one described above, it's better to make separate exposures on small pieces of enlarging paper — about 2 x 2 inches in size — after first writing the exposure on the back of each in pencil. Process them together to save time.

After deciding on the best exposure, turn out the room lights and expose a full size piece of enlarging paper. After processing, you must fully wash your print to remove chemicals that would otherwise badly stain the paper. RC papers should be washed for five minutes, and conventional papers for 20 minutes or longer in your bathtub or sink. Let the tap run slightly to maintain the continuous circulation of fresh water, swirling the prints occasionally to keep them from sticking together. After washing, wipe the excess moisture from the prints using a soft sponge; then let them dry face-up on a towel. RC papers dry fairly flat, but regular papers will curl; a day or two under heavy books will usually flatten them.

Good printing requires practice, but it won't take long before you'll make better astroprints than most commercial processors do. The best way to get the snappy prints all astrophotographers want is to establish good habits in your darkroom work right from the start — clean negatives and hands, precise and consistent development time, and use of fresh and uncontaminated solutions. If you observe these simple rules scrupulously, you'll avoid 80 percent of the print quality problems common among astrophotographers.

Editor's Note: Another article on specialized printing techniques and their applications in astrophotography will appear next month.



Is Faster Better?

by

Brad Wallis and Robert Provin

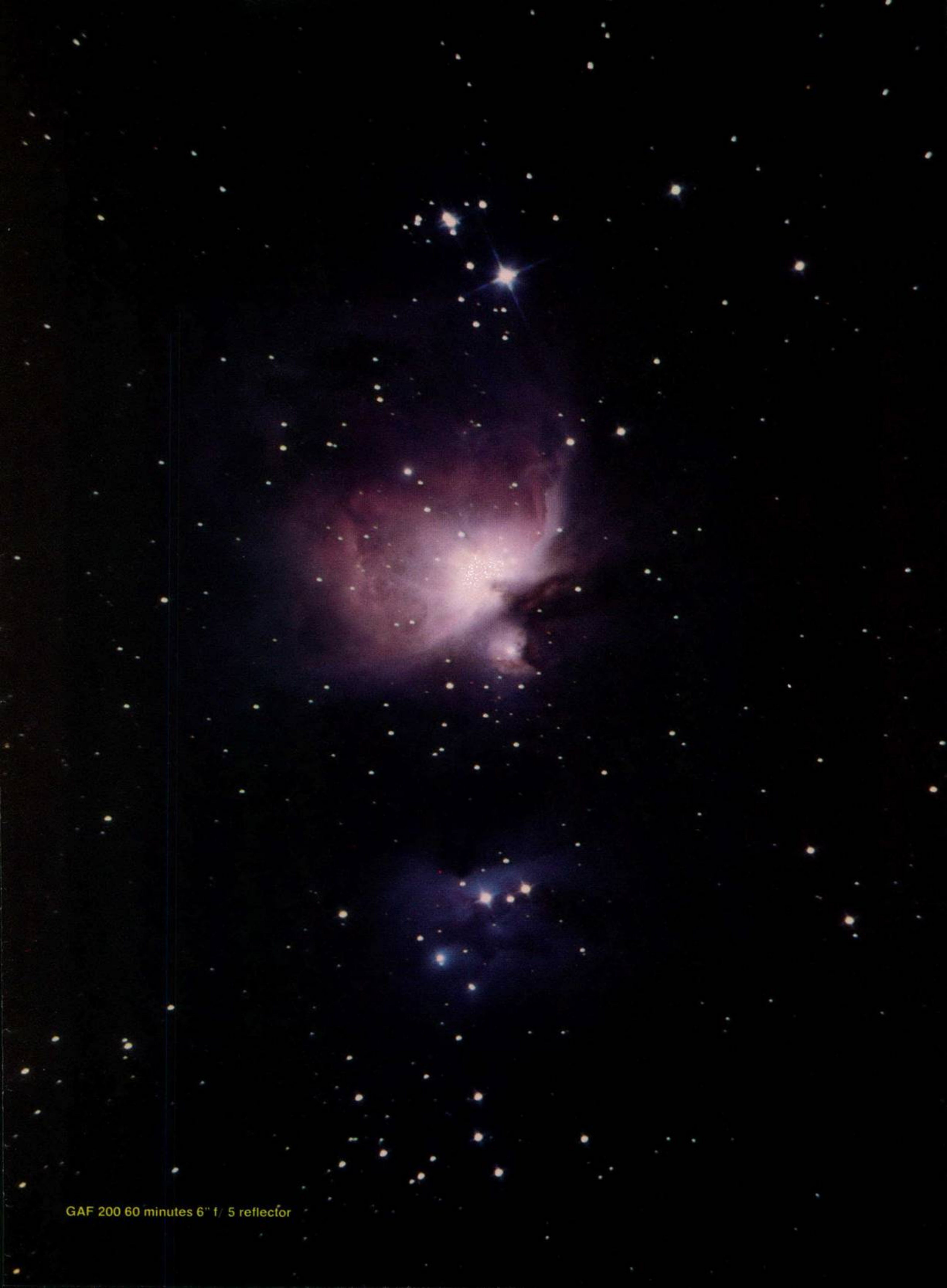
Does the fastest color film always give the best results? Given the vagaries of graininess, reciprocity failure, satisfactory color rendition, and variation in processing from one film developing lab to the next, only actual sky tests can provide the answer. In this simple comparison test, two films produced by the same manufacturer — one rated at ASA 200 and the other at ASA 500 — were exposed in the same telescope, on the same object (the Orion nebula), for times ranging from five minutes to one hour. The results show that the slower film, GAF 200, is in fact the better film for astrophotography.

While film comparisons using short focus lenses (see "Which Color Film Should I Use?", ASTRONOMY, October 1974) are valid for checking a film's ability to record stars, they are not always a measure of the film's ability to record nebulae, so actual telescope tests are required.

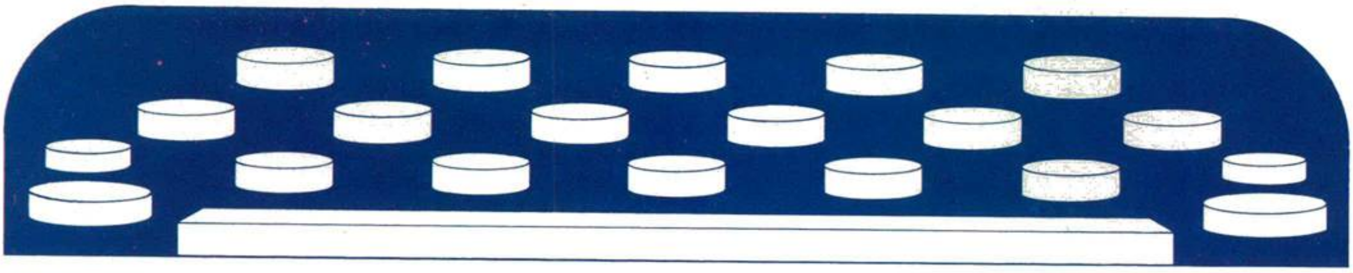
In testing films, it is important that variables not related to the film must not obscure the differences between them. Thus, all exposures were made when the object was near the meridian, when seeing and transparency were excellent, and, of course, all were taken through the same instrument — a six inch f/5 homemade reflector.

Of the two, GAF 500 is grainier, records background skylight more slowly, has higher contrast and somewhat more intense color rendition. It is, however, approximately 1/2 as fast in recording the same nebular wisps as GAF 200. GAF 200 records red and blue details in the nebulae with about equal speed, is less grainy than GAF 500, has excellent latitude in exposure, and has less contrast but better color rendition than GAF 500.

In processing variation, GAF 200 also appears to be better: When home-processed, GAF 500 has a different color balance than when lab-processed, whereas GAF 200 comes out the same. Among the work done by film labs, poor processing is more common than good processing; so if you find a good reliable lab, stick to it loyally.



GAF 200 60 minutes 6" f/ 5 reflector



IN FOCUS

Sir / In the November 1974 issue, there was a picture (page 34) of the "cluster" of moon and planets that took place in August 1966. I am very curious as to when this event will happen again. Can you tell me?

JORGE H. JAIME
Pharr, Tex.

Mr. Jaime / The event you are referring to is called a "conjunction". Conjunctions between the moon and a planet are fairly frequent; those involving two or more planets are rarer. Conjunctions in 1977 will take place on Feb. 12 (Mercury and Mars), June 3 (Venus and Mars), July 30 (Venus and Jupiter), Sept. 4 (Mars and Jupiter), and Sept. 18 (Venus and Saturn). From 1977 to 1982, the outer planets will be aligned on the same side of the sun providing a real treat for observers who enjoy conjunctions!

Sir / While reading your October issue, I came across what appears to be a misprint. In the Astro-News article, "Construction Continues on VLA Radio Telescope", you state that "the most skittish known quasar is estimated to be six trillion light-years away." Isn't the six trillion figure in error?

JOHN K. KUNDRA
East Hartford, Conn.

Mr. Kundra / You're right — the figure should be six billion. The error arose from a faulty transliteration of the figure "six thousand million" — the British term for our number six billion. In British terminology, "six billion" is identical to the American six trillion.

Sir / On the night of July 22, 1976, I observed two odd things. Just before 10:30 p.m., a seventh or eighth magnitude starlike object with a red-yellow tint entered my telescope's field of view, traveling north about one degree in two seconds. Last year I observed a satellite that my telescope resolved to a disk — unlike the July 22 object, which was just a pinpoint of light.

About 11:35 p.m., something else flashed across my field of view. I think it was a meteor, since it moved through the field in a split second. It passed so quickly and unexpectedly that I can say only that its magnitude was between five and eight.

Can you tell me what these objects might have been?

PATRICK TOBEY
Milltown, N.J.

Mr. Tobey / Your guess is right on the second object; undoubtedly you observed a meteor that just happened to cross your field of view. Such occurrences are not terribly uncommon.

Even if you could not resolve your first object into a disk, a satellite is what you saw. Keep in mind that satellites come in many different sizes and orbit Earth at many different altitudes, and your telescope is not likely to be able to resolve them all.

Sir / Where can I find information concerning the number of stars in different globular clusters? I'm aware that the range of the number of stars within globulars is approximately 1,000 to 1,000,000. However, I'd like to know more specific statistics on individual clusters such as 47 Tucanae, Omega Centauri, M-2, M-13 and NGC-2419 in Lynx.

JAMES R. CYPSER
Poughkeepsie, N.Y.

Mr. Cypser / You are asking for a statistic which, at the moment, is impossible to determine with any certainty. About all we can do is make estimates, but not even the best observatory photographs can come close to showing exactly how many stars are contained in a globular cluster. Incidentally, the first figure you mention is far too small; almost all the globular clusters known hold at least 100,000 stars.

You can find various bits of information about the globulars that are on the Messier list in this month's Gazer's Gazette.

Sir / I recently read the article "Red Light Sky Photography" in the August issue, and found it particularly interesting because I had just purchased a 125 foot roll of spectroscopic 103aE film. Since the sun and solar prominences (and corona?) also emit light at the Hydrogen-alpha wavelength, I was wondering if there is some relatively cheap method by which I could get good pictures of prominences and possibly the corona using spectroscopic film.

I also enjoyed, in the July bicentennial issue, the article dealing with old Indian legends explaining the constellations and the Milky Way. Would you know of any books dealing specifically with those legends?

KEVIN HUBBARD
Skokie, Ill.

Mr. Hubbard / Taking your questions in order: You can obtain pictures of solar prominences, but you'll need an interference filter because of the narrower band width of the spectrum required to separate the sky background from the H-alpha wavelength. Unfortunately, you can't get photographs of the corona because it is an extremely weak emitter of radiation at any wavelength, and H-alpha filters won't make your results any better (or worse). ASTRONOMY will soon be running an article on solar H-alpha photography.

The information in "Skylore of Indigenous Americans" was obtained from several different sources, including an encyclopedia of mythology. To the best of our knowledge, there is no single book currently available in which all this material is presented.

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ASTRO-NEWS

Latest News From the World of Astronomy

Possibility of Evaporite Deposits Contribute to Martian Water Theory

Shortly after Viking 2 landed on Sept. 3, 1976, it returned photos revealing a flat landscape littered with rocks up to three feet across, resembling dark gray basaltic lavas of Earth. After Viking 1's dunes, rocks and hills, the Utopia plains looked rather monotonous to Viking scientists who had hoped for a touchdown in terrain even more varied than the Viking 1 site.

But one feature of special interest caught scientists' eyes. A shallow, gullylike depression lay northeast of the lander. To Viking geologists, it resembled the small, eroded arroyos, or dry riverbeds, found on Earth. A foot or two across, it seemed freer of rocks than the surrounding terrain, perhaps being partly filled with drifts of Martian dust.

Near the closer end of this channel was an eight by nine inch patch of light colored, layered, crusty looking soil. This patch reminded Viking geologists of terrestrial deposits called *evaporites* — minerals formed from dissolved salts and deposited as water evaporates. One example is *caliche* — a white calcium carbonate/calcium sulfate material found in desert soils. Another example is the whitish material that forms bathtub rings in hard water areas.

With tongue in cheek, the Viking staff began referring to this patch as the "Bonneville Flats", after Earth's famous region of flat evaporite deposits. More seriously, they speculated that this eight by nine inch patch might really be remains of an evaporite deposit. Measurement of an evaporite-like composition such as calcium carbonate would be strong evidence for the emerging theory that Mars had abundant flowing water in many parts of its surface at some time in the past.

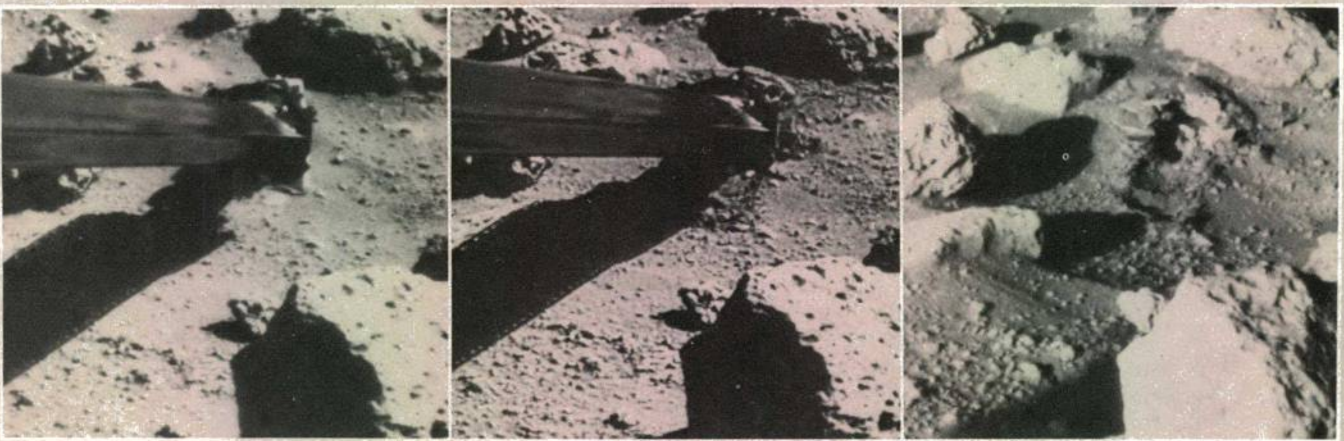
There was even thought that such patches might be widespread, since other less pronounced bits of crusty soil were scattered around the landing site, and similar bits had been seen in the region swept by Viking 1's lander engines. On the other hand, color pictures showed that the spot was as red as the rest of the soil, even though a bit lighter.

The spot was chosen as a target for sampling. It was a hard place to reach with Viking 2's sampler arm, since it could be seen with only one camera, ruling out the stereo coverage normally used to guide the arm. However, on Sept. 25, Viking technicians guided the arm unerringly to the layered soil and scooped the first sample processed by the Viking 2 elemental abundance experiment. (One earlier sample had gone to biological experiments on Sept. 12.)

Initial evaluation of the composition measurements showed that the composition was very close to — if not identical with — composition of soil sampled at the Viking 1 site. That site was found to contain silicate minerals and not to be composed of pure carbonates, hydroxides or similar nonsilcate materials. The calcium content at the Viking 1 site was estimated at only three to eight percent, and the measurements from the Bonneville Flats, still being reduced, are apparently similar.

Inorganic chemistry team member

Viking *continued on page 56*



The Viking II surface sampler is shown in a sequence of photos that depict the sampling process. The photo at left shows the scoop touching the surface, missing the rock at upper left by about six inches. The center photo was taken eight minutes after touching the surface. The photo at right (note different lighting) shows the 3 inch wide, 1-1/2 inch deep trench. NASA photographs.

Chemist Invalidates Tunguska Hypothesis

Theories that the 1908 Tunguska, Siberia, explosion was caused by some sort of nuclear reaction are invalid, according to chemist William F. Libby. The Nobel prize laureate (father of the carbon-14 radioactive dating method) was responding to Russian theories that the tremendous explosion might have been caused by a natural or extraterrestrial thermonuclear detonation.

In 1965, Libby and two coworkers analyzed carbon-14 levels in tree rings taken from an old tree in Arizona. The scientists were looking for possible high levels of the isotope carbon-14 (the most common form of carbon is carbon-12), which might indicate that a nuclear process caused by antimatter had occurred.

Calculating that the antimatter theory for the Tunguska explosion would have required a determinable amount of neutron emission — which would in turn have resulted in an easily calculated level of carbon-14 increase — Libby searched for such an increase in rings grown by the tree in 1909, the year following the blast.

The absence of any marked change in the carbon-14 level led Libby to place a maximum upper limit on the size of the postulated nuclear reaction. It was far too small to account for the Tunguska explosion as a matter/antimatter reaction. For this and other reasons, the antimatter theory of the Tunguska event has fallen into disrepute.

In a recent dramatized book about the Tunguska event, two drama critics use Libby's results to discredit the antimatter theory while plugging their own version of events, suggesting that the explosion was a nuclear blast resulting from the failure of the atomic power plant of an extraterrestrial spacecraft.

Responding to this suggestion, Libby pointed out that his tests ruled out *any* nuclear reaction of the size required to account for the 20 megaton Tunguska explosion. Had it been a thermonuclear fusion reaction, Libby continued, his test would easily have detected evidence to that effect. Instead, his test showed no trace of the inevitable by-products of a nuclear explosion of that size. Other tests made in Europe also confirm Libby's results.

Astronomers continue to study the Tunguska event and possible related meteoric explosions. The link between such midair disintegrations and burnt-out comet nuclei has received recent support. The comet theory (first proposed in 1930) is probably growing stronger year by year.

Viking *continued from page 55*

Harry Rose, interviewed by ASTRONOMY, noted that the crusty material is certainly not pure calichelike calcium carbonate ($CaCO_3$), but pointed out that it could contain some mixture of evaporite minerals, including some carbonates or sulfates.

Imaging team member Elliot Morris, interviewed by ASTRONOMY, said that evidence for well-developed evaporite deposits is now weak, noting that other processes can compact the surface layers of soil in deserts.

Of course, if most Martian water ran a billion or more years ago, as geologic analysis of the orbiter photos suggests, it would be unexpected to find small scale surface evaporite deposits still preserved in the dusty, windy environment of Mars. However, orbiter measurements of traces of water vapor in today's Martian air suggest to some Viking chemists that a daily transfer of moisture occurs from the soil to the air, and back. Moisture may be absorbed onto rock particles, occasionally being liquid. The best guess, then, is that the Viking landers may have found evidence of a modestly effective cementing process in the surface soil of Mars, possibly due to leaching of salts from rock particles under modern conditions, forming minor traces of evaporites such as sulfates or carbonates in undetected amounts. But apparently the Viking landers have not turned up evidence of full-fledged evaporite deposits such as found in dry lakebeds in terrestrial deserts. Since the Martian desert surface seems controlled by windblown dust, thick, ancient deposits would not be expected in random landing sites. Probably it is the wind's mixing of the dust from many regions of Mars that accounts for the general similarity of composition at the Viking 1 and 2 sites, more than 4,000 miles apart.

This report was filed by ASTRONOMY magazine's Viking correspondent, William K. Hartmann.

Viking Life Results Pessimistic

The three experiments designed to seek life on Mars have all produced what might be called "ambiguous positive" results in tests at Viking 1 and 2 landing sites. But the trend in the interpretations is toward a negative answer to the question of life on Mars.

The experiments are designed to examine chemical changes that accompany an environment with living organisms. These changes are sought in chambers into which Martian soil is placed. In all tests, the predicted type of chemical change has been found, but not with the rates expected on the basis of tests of Earth organisms. Instead, behavior of the samples has led many biologists and chemists — both inside and outside the Viking project — to suspect that nonbiological chemical changes in the soil are responsible for the test results. Bombarded by ultraviolet radiation from the sun, the oxidized minerals of Mars present a different chemical environment than that found on Earth.

A fourth experiment having decisive impact on the interpretation is an instrument that analyzes the chemical composition of Martian soil. This could reveal the heavy, multi-atom, complex molecules of substances that exist in all organisms. These molecules are required to carry out the consumptive and reproductive processes of life as we define it. They would have accumulated in the soil if life had existed recently. Yet none of these molecules have been found native to Mars at either the Viking 1 or 2 site.

Though Viking scientists are not quite ready to rule out life, the mood at the Jet Propulsion Laboratory is that life probably does not exist now, nor has it in the recent past at the Viking sites. At a mid-October press conference, Viking scientist Gerald Soffen cautioned that we have only sampled two sites and are not even sure of the interpretation there. He wished for samples of deeper soil, a few meters down. A last hope is that soil from underneath the rock moved on Oct. 8, 1976, having been protected from solar ultraviolet rays, may reveal something different.

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Space Shuttle Orbiter Unveiled: Target Date Set For Early 1979

America's new space vehicle, the winged Space Shuttle, is now a reality. In a ceremony at its construction plant in Palmdale, Calif., the Space Shuttle vehicle number 1 was "rolled out" before hundreds of space dignitaries, rocket engineers, members of the press, and several actors in the former television series "Star Trek". NASA organized the Sept. 17 event to introduce the rocket plane to the nation.

The vehicle shown was the Orbiter section of the whole space launch system. When orbital missions begin in early 1979, a large external tank (with fuel for the Orbiter's three Space Shuttle Main Engines) and two solid-fuel rocket boosters will also be attached to the Orbiter section. They will be jettisoned on the way into space; the solid rocket boosters (SRBs) will fall back to Earth and be recovered for reuse, while the external tank (ET) will burn up in the atmosphere. Following its mission, the Orbiter will return to Earth, landing on a two mile long airstrip.

Since these spacecraft will be used over and over again, they are true spaceships and not throwaway onetime space capsules. Hence, NASA decided to give each vehicle the name of a ship made famous in early American history.

Originally, Orbiter 101 (as the vehicle shown last September is officially known) was to have been christened Constitution. However, in response to a massive letter campaign from "Star Trek" fans, President Ford named the spaceship the Enterprise.

Plans for the Enterprise include extensive flight testing at Edwards Air Force Base in California, where NASA operates its Dryden Flight Research Center. Early next year, the Enterprise will be wheeled overland from Palmdale to the Dryden Center along a specially prepared route and causeway. The total distance of about 20 miles will be covered at three m.p.h. (The design speed of the Enterprise is 18,000 m.p.h.)

Transporting the Orbiter from factory to Cape Canaveral would be impossible by land, so alternate schemes have been developed. Too big to fit into another aircraft or be slung under the wing of any aircraft, and too heavy to travel by rail, the Orbiter will be flown piggyback atop a modified Boeing 747 cargo plane. Test flights of the unique configuration will be made from the Dryden Center beginning in February 1977.

To test the landing characteristics of the Orbiter, manned drop tests will also be made in 1977. Astronaut crews will pilot the 75 ton space glider to "dead stick" landings after being separated from the carrier aircraft. The first drop test (NASA calls them Approach and Landing Tests, or ALT series) will be made in July.

Two pairs of astronauts have been selected to take turns flying the ALT missions over a test program of six or more drops. The first flight will be made by astronauts Fred Haise and Charles Fullerton, while later flights will be made by Joe Engle and Dick Truly.

Since the Enterprise will only be making five minute glide tests at speeds no greater than several hundred m.p.h., many features of the operational Orbiter vehicle will not be installed for ALT. The main rocket engines will be simulated by ballast dummies, as will the orbital maneuvering system rockets. There will be no fuel cells, heat exchangers, stellar navigation instruments or rendezvous radars. The thermal protection system (TPS) insulation tiles will be simulated by plastic tiles which weigh the same and have the same air drag.

Extra equipment will be on board, including two standard jet aircraft ejection seats. In case of control problems after separation from the 747, the two astronauts can eject safely from the doomed Orbiter.

Following the 1977 flight tests, the Enterprise will be ferried by air to the Marshall Space Flight Center in Huntsville, Ala. The Orbiter will be mated to test SRBs and an ET, set up vertically in a special test tower, and subjected to vibration launch into orbit. When this program is completed late in 1978, the Enterprise will be returned to the Palmdale factory for conversion into a flight-ready vehicle.

Meanwhile, Orbiter 102 — which will be the first Space Shuttle to actually fly into space — will have been under construction. Its missions will begin in early 1979 from Cape Canaveral, where the old Saturn launch complex has been modified, and where a long landing strip is also being built. The first landings of what NASA calls the Orbital Flight Test program (or OFT) will be at the Dryden Center, after which Orbiter 102 will be air ferried back to Cape Canaveral for another flight.

The Enterprise will make its first orbital flight in early 1981, followed a year later by Orbiter 103 (the third name selected by NASA is Constellation). These vehicles, and two additional Orbiters under development, will support weekly flights into orbit by the middle of the 1980s.

The Orbiter is limited to flights in low Earth orbit, perhaps up to 600 miles or higher with small payloads and additional rocket fuel. To send satellites into higher orbits or out to the moon and planets, an additional rocket stage will be needed. Shortly before the Enterprise was rolled out, an aerospace contractor for this upper stage was selected.

Since later configurations of the shuttle will carry a much more sophisticated rocket, the present solid-fuel booster is called the Interim Upper Stage. It is being built by Boeing for the United States Air Force, which will make units available to NASA, just as NASA will make Space Shuttle flights available to military payloads.

MAIN ENGINES BEING TESTED

As the Space Shuttle is prepared for service, testing of the Space Shuttle Main Engine (SSME) proceeds at a rapid rate. Static test firings of increasing frequency and longer duration are currently being made at the National Space Technology Laboratories (NSTL) in Bay St. Louis, Miss. The longest test firing of the SSME to date was made in late September; one of two engines was successfully fired for 650 seconds at mainstage operating levels (50 percent rated thrust level).

The current series of tests is designed to obtain component and systems operation data. Long duration firings are being carried out at gradually increasing power levels above mainstage. Other important parameters such as engine throttling control, engine start and shutdown sequence, and engine power balance have been tested in previous firings.

Each Space Shuttle engine will be fired at NSTL before being certified for flight. The testing is being carried out under the direction of NASA's Marshall Space Flight Center in Huntsville, Ala.

Soviet Moon Drill Pioneers a New Automated Lunar Exploration Phase

The success of the Soviet Union's Luna 24 moon drill may open a new phase in the Soviet program of automatic exploration of the moon. The retrieval of lunar soil from a depth of two meters (6.56 feet) was accomplished after more than two years of delay and earlier failures. Other projects which were postponed until after the success of this special effort can now be carried out.

The flight of Luna 24 last August carried out the third retrieval of lunar samples by Soviet unmanned probes. In 1970, Luna 16 brought back 100 grams (about 3.5 ounces) of soil drilled to a depth of 350mm, and in 1972, Luna 20 brought back an additional 50 grams. Total samples collected by six manned Apollo missions weigh 380,000 grams. Moscow has not disclosed the weight of the Luna 24 samples, but specialists estimate that they weigh several hundred grams.

The 5,800 kilogram (about 6.5 tons) spacecraft was launched from Russia's central Asian space center by the largest operational Soviet space booster, the "Proton". After orbiting the moon for four days and casting off excess fuel tanks, Luna 24 made a soft landing in the Mare Crisium.

A remote controlled drill arm positioned the drill head over an area selected by ground controllers via television. The drill operated for several minutes and penetrated two meters, extracting a core about eight millimeters wide. The drill tube was coiled up and inserted into the return capsule atop the vehicle's ascent rocket stage.

The next day, the ascent stage blasted off from the moon. After a 3-1/2 day return trip, the 40kg entry capsule (with a diameter of about 1/2 meter) plunged into Earth's atmosphere over the Soviet Union. The direct descent with an entry angle of greater than 30 degrees resulted in deceleration forces of 300 times the force of gravity.

At an altitude of 15 kilometers (9.32 miles), the probe's small parachute opened and a recovery beacon began to transmit directional signals. Recovery crews in helicopters heard the beacon and closed in, but did not reach the touchdown area for several hours.

The sample was taken to a special receiving laboratory at the Vernadskiy Institute in Moscow. The pressurized sample chamber had been sterilized with hydrogen peroxide, pumped down to a vacuum, and then repressurized with helium.

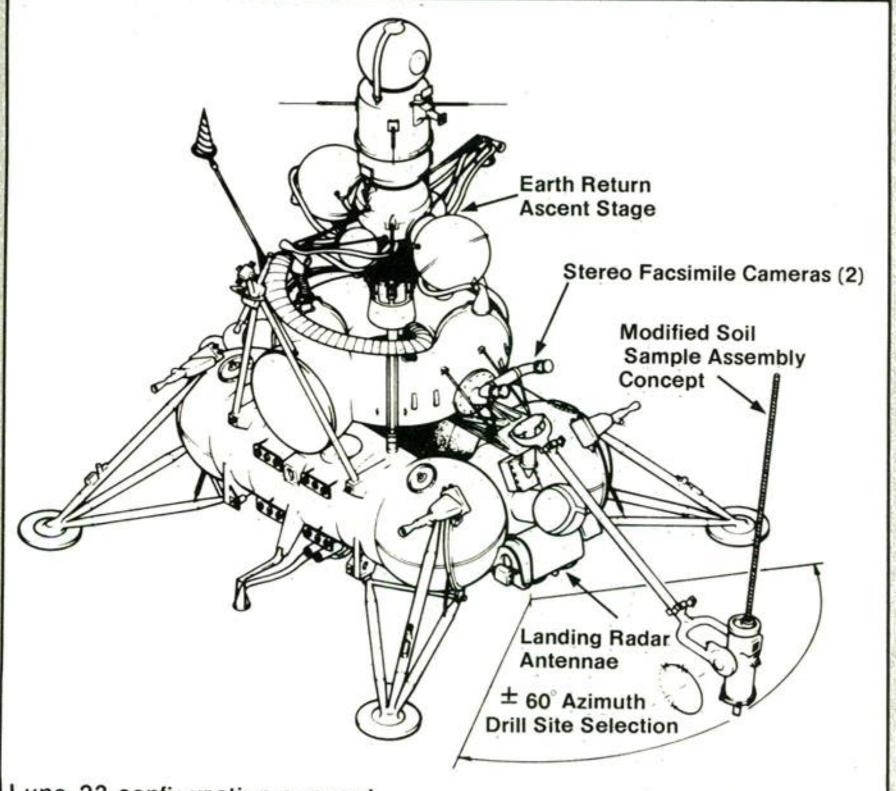
Soviet scientists reported that their choice of the Mare Crisium site was based on its relative low elevation and possible comparative youth, as well as by the mass concentration (mascon) detected below the surface of the round impact basin. Initial results from analysis at the Vernadskiy Institute were promising, as scientists detected several distinct layers of deposition, and different densities in the layers. Both fine dust and small particles were collected.

As with previous lunar samples retrieved by the Apollo and Luna programs, scientists throughout the world will share in the analysis. American lunar geologists are expected to be invited to Moscow early in 1977 to receive several representative selections from the lunar core sample.

American scientists are eager to compare this set of deep samples with cores made on Apollo 15 (two drillings to depths of 1.6 meters) and Apollo 17 (two drillings to depths of 2.6 meters).

Although Soviet commentators continue to stress the economy, flexibility and safety of unmanned lunar exploration relative to manned programs, the Luna 24 flight does not bear out their contention. As to cost, Washington, D.C. Soviet space analyst Charles Sheldon (of the Congressional Research Service of the Library of Congress) recently estimated that a Soviet robot moon probe probably costs about 20 to 25 percent the price of a manned expedition, but that a dozen unmanned launches would be required to approach the scientific returns of a single manned shot. As to flexibility, all Soviet sample return missions have been restricted to the far eastern equatorial regions of the moon due to severe constraints on guidance of the return flight. There are not an infinite number of interesting sites in this small area of the moon.

Soviet scientists will continue to study this new lunar sample, while Soviet space engineers proceed with new lunar probes. It has been several years since the last Lunakhod moon rover was placed on the lunar surface, and another flight of this kind is expected shortly.



Luna 23 configuration concept

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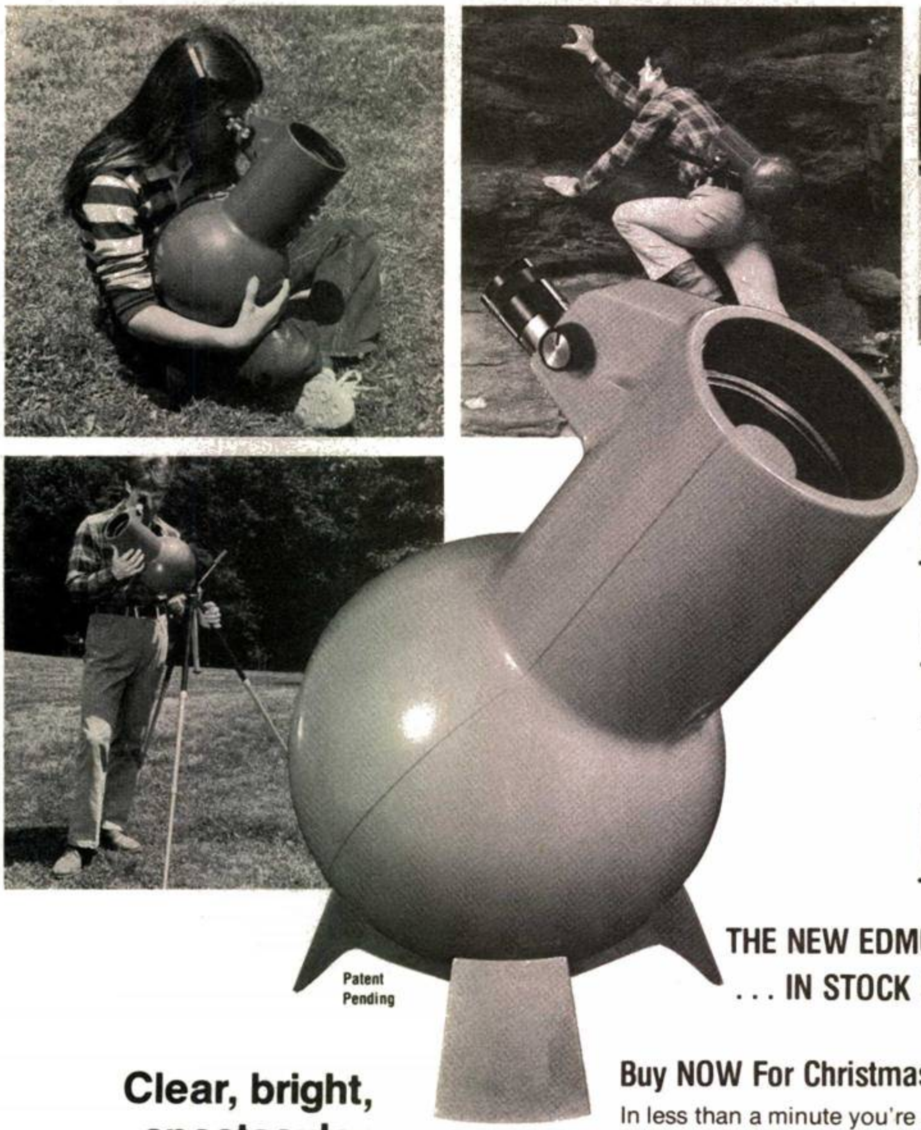

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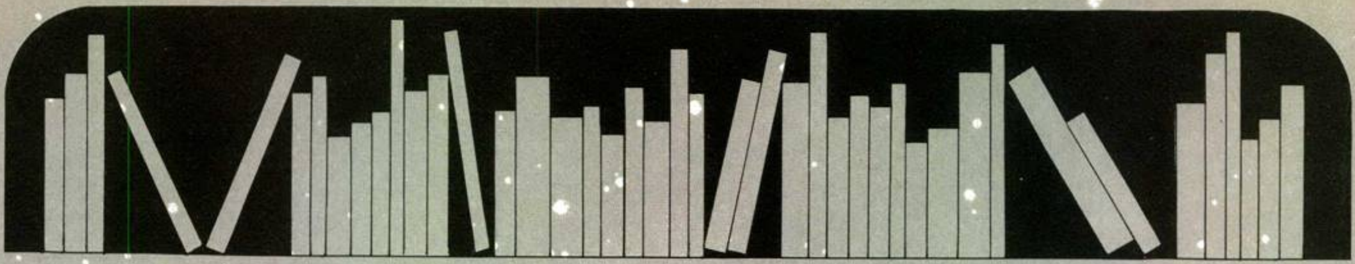

Strange Universe — A Sourcebook of Curious Astronomical Observations

compiled by WILLIAM R. CORLISS

279 pages, hardcover, $7.95
The Sourcebook Project (1975)

This volume is one in a growing series of sourcebooks (currently numbering seven) providing in handy looseleaf format a remarkable collection of unusual and unexplained observations in various fields of science. **Strange Universe** deals with astronomy, and so is of special interest to readers of ASTRONOMY.

Although his work has been likened to that of a modern day Charles Fort, Corliss simply calls himself a compiler of the vast amount of material presented. However, he has done an incredible job of research, culling overlooked and forgotten enigmas from a multitude of scientific journals and publications dating from before the invention of the telescope right up to the present day.

Complete references for each entry in the sourcebook are provided, but interpretation is carefully left to the imagination and resourcefulness of the reader. Here is abundant food for mind-expanding speculation and investigation!

Sections dealing with anomalous observations of the moon and planets are sure to interest the amateur astronomer who enjoys using his telescope. A good observer should always approach the eyepiece with a sense of anticipation — on the lookout for anything unusual, be it a moving light on the lunar surface or supernova outburst in one of Messier's galaxies.

Strange Universe is guaranteed to keep you alert at the telescope, and will probably change your outlook on science as well. The author has done an immeasurable service in resurrecting so many unsolved mysteries from a death of obscurity and indifference, bringing them to the light of day for fresh minds to ponder. *James Mullaney.*

* * *

X-Ray Binaries

edited by ELIHU BOLDT and YOJI KONDO

758 pages, paperback, $16.25*
NASA (1976)

This is another case of scientific overkill: You can read much more than you ever wanted to know about x-ray binaries. Every paper presented in a three-day NASA symposium in late 1975 is reprinted in full.

For those already interested and somewhat familiar with the topic, this collection could be a valuable source. Recent satellite and rocket tests are described. Individual panels then discuss specific x-ray sources: Hercules X-1, Centaurus X-3, Cygnus X-1 and X-3, the transient source AO-620, and two others. Other possible x-ray binaries are also discussed. Observational programs with a wide variety of instruments are described.

Behind all the technical papers is an informal organization of astronomers devoted to a coordinated world program for observation of x-ray binaries. The astronomers exchange information, suggestions and recommendations, and also try to designate specific dates for combined observations. (Here they ran into serious problems with the long lead time of scheduling ground telescopes versus the quick decisions made with satellite observatories.)

The collection contains few general survey papers; even good introductory remarks are rare. The book could be far more interesting to the astronomy enthusiast with the inclusion of a summary of "knowns" and "unknowns" about Hercules X-1.

According to panel chairman John Bahcall, "Among the properties we can regard as understood are: the origin of the 1.7 day period (cause: binary motion); the origin of the 1.2 second period (cause: the rotation of a compact star); the origin of x-ray emission (cause: mass accretion onto a compact star); the origin of the large optical variations (cause: x-ray heating of the photosphere of Hz Herculis)." But some of the "more obvious, incompletely understood phenomena" include the origin of a 35 day period, the origin of historically long inactive periods, the nature and origin of the x-ray spectrum and pulse shapes, and an explanation for occasional optical pulsations. Now, with this list in mind for reference, the reader can examine the panelists' papers with a sense of perspective and a real feel for the exciting mysteries of this initially somewhat esoteric specialization.

In a discussion on Nova Monocerotis 1975, the transient x-ray source AO-620-00, NASA astronomer Stephen Maran summarizes the little that is known, the much that is asked, and the bit that is guessed about this strange but not unique object, and ties it to the question of recurrent novae and possible black holes.

With these observations, generalizations leading to new theories become possible.

Dozens of possibilities have been suggested but not yet observed, says Herbert Gursky, adding: "It is likely that we have only just begun to unravel the diversity of physical conditions leading to x-ray emission from galactic objects."

This book shows how knotty the unraveling can be, and also how far this entirely new astronomy may be able to see. *James E. Oberg.*

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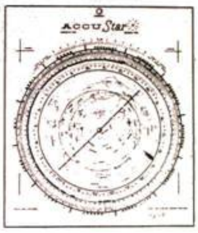

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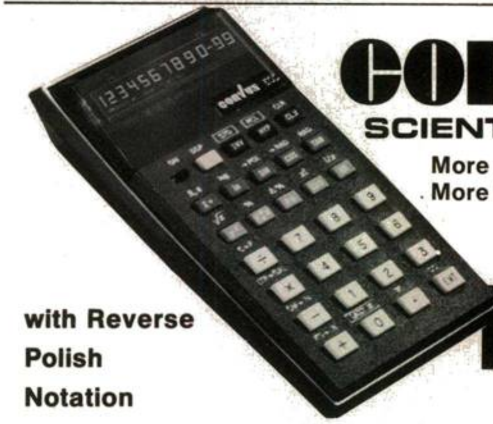

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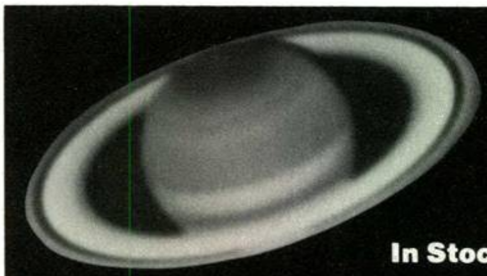

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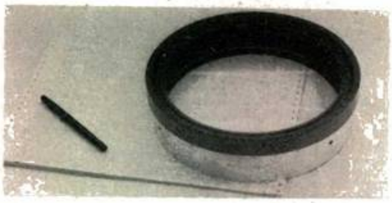

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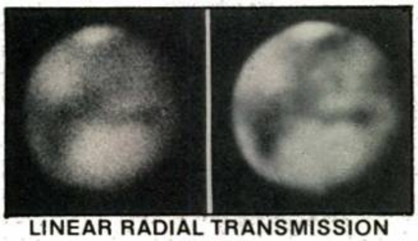

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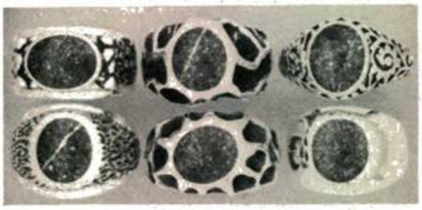

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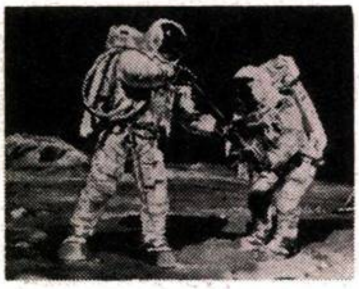

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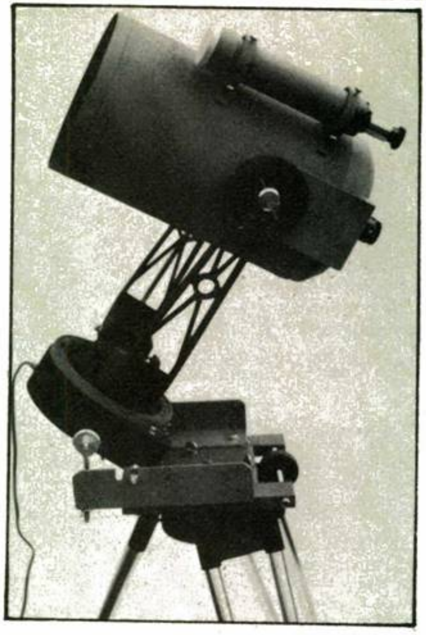

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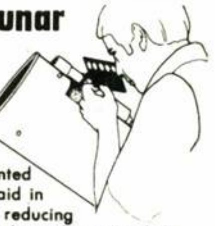

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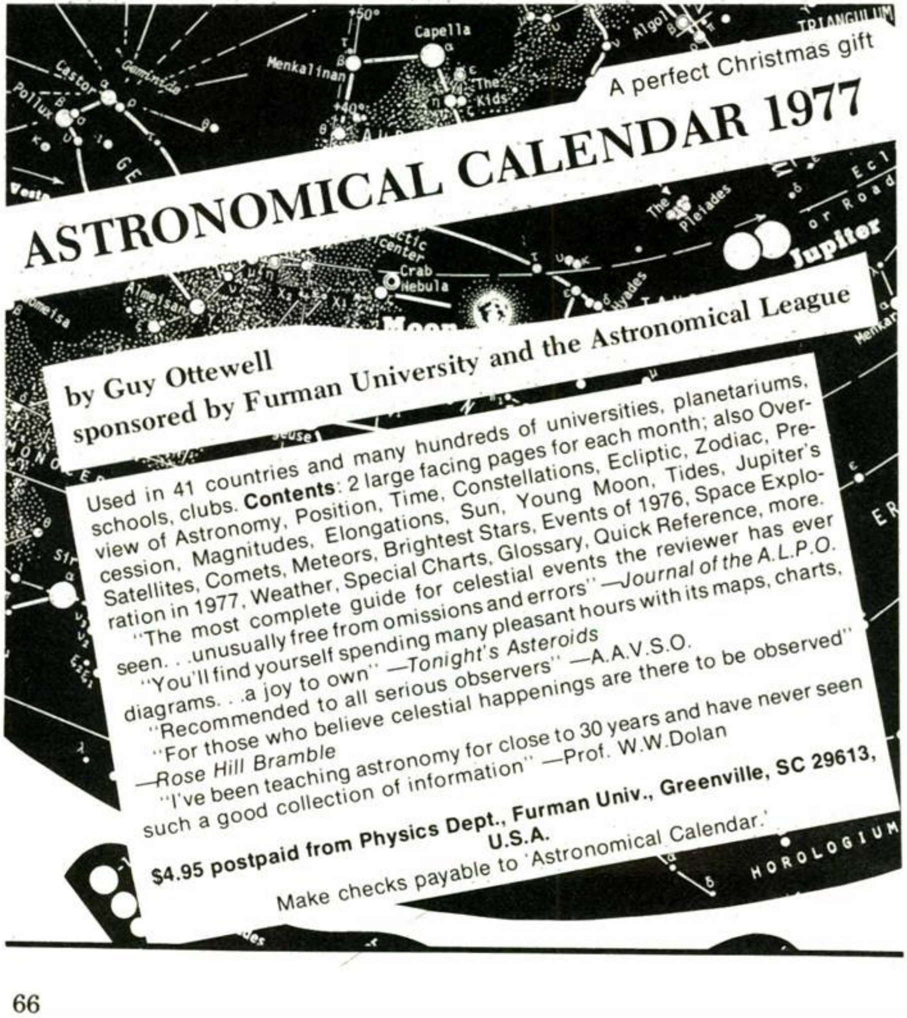

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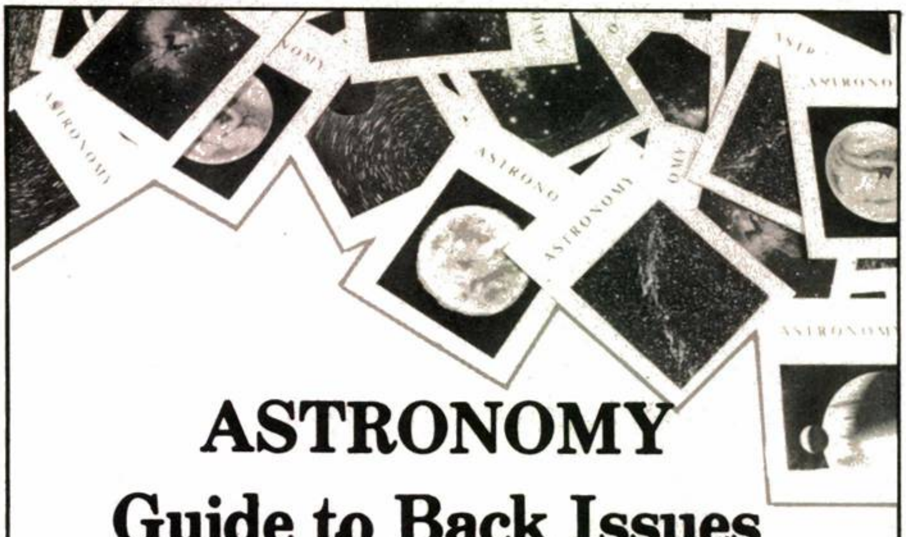

ASTRONOMY

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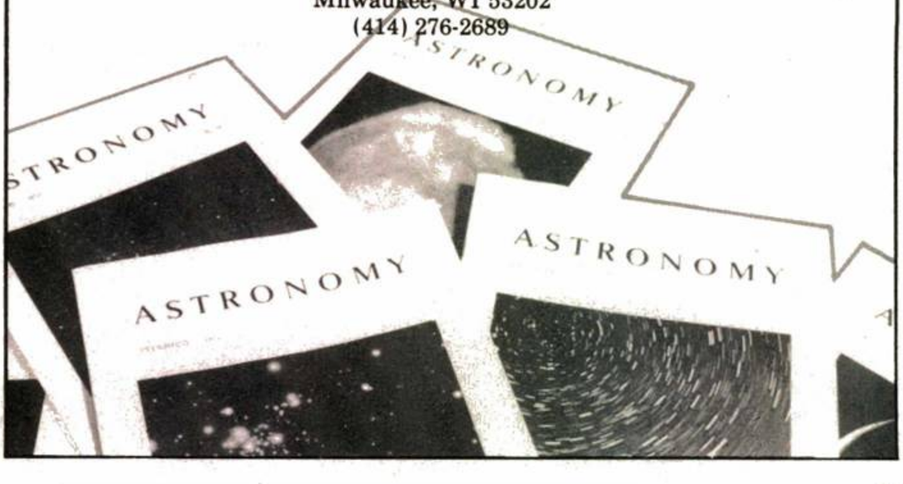
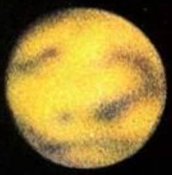


Planet Finder

Ⓒ Ceres

Dec.	1	15
R.A.	12h05m	12h22m
Dec.	+10°08'	+9°09'
Mag.	+8.2	+8.0



Ⓐ Mercury

Dec.	1
R.A.	17h30m
Dec.	-25°24'
Mag.	-0.5

Ⓑ Mercury

Dec.	15
R.A.	18h59m
Dec.	-24°50'
Mag.	-0.5

Ⓜ Mars

Dec.	1	15
R.A.	16h24m	17h08m
Dec.	-21°57'	-23°22'
Mag.	+1.6	+1.6

Ⓝ Neptune

Dec.	15
R.A.	16h51m
Dec.	-21°02'
Mag.	+7.7

SUN

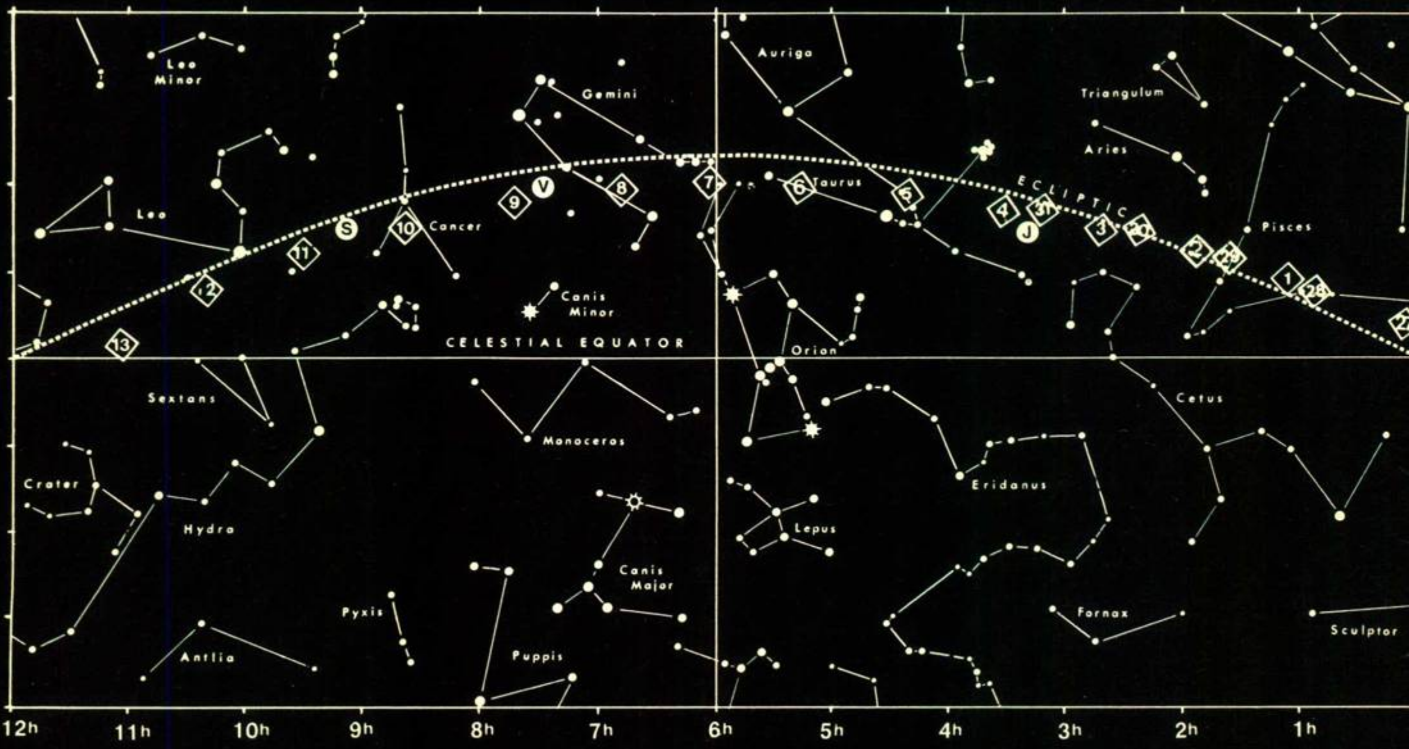
The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

Ⓢ Saturn

Dec.	1	15
R.A.	9h18m	9h17m
Dec.	+16°32'	+16°39'
Mag.	+0.5	+0.4

Ⓤ Uranus

Dec.	15
R.A.	14h31m
Dec.	-14°27'
Mag.	+5.7

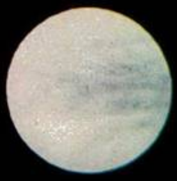

Leo Minor
Gemini
Auriga
Triangulum
Aries
Leo
Cancer
Taurus
ECLIPTIC
Pisces
Canis Minor
CELESTIAL EQUATOR
Orion
Sextans
Cetus
Monoceros
Crater
Eridanus
Hydra
Lepus
Canis Major
Pyxis
Fornax
Sculptor
Antlia
Puppis
13
12
11
S
10
9
V
8
7
6
5
4
31
J
3
30
2
29
1
28
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec. = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag. = magnitude, a

December 1976

Ⓥ Vesta

Dec.	1	15
R.A.	7h50m	7h43m
Dec.	+20°18'	+21°10'
Mag.	+7.5	+7.3



Ⓙ Jupiter

Dec.	1	15
R.A.	3h28m	3h22m
Dec.	+17°47'	+17°26'
Mag.	-2.4	-2.3

Ⓨ Venus

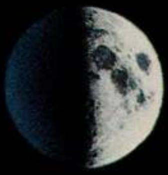
Dec.	1
R.A.	19h32m
Dec.	-24°02'
Mag.	-3.6

Ⓩ Venus

Dec.	15
R.A.	20h42m
Dec.	-20°29'
Mag.	-3.7

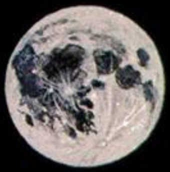
Ⓟ Pluto

Dec.	15
R.A.	13h16m
Dec.	+10°09'
Mag.	+14



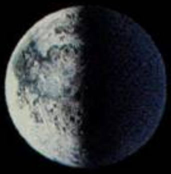
First Quarter

December 28



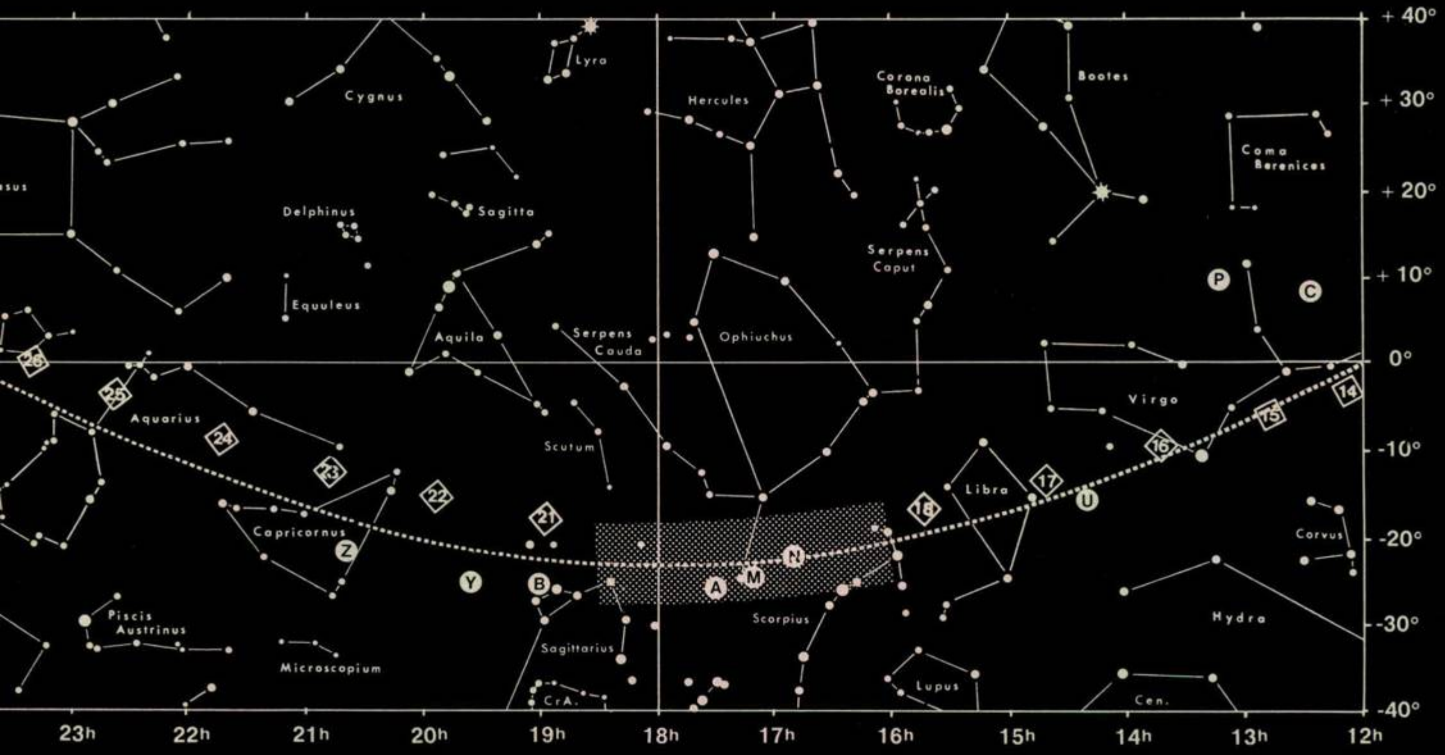
Full Moon

December 8



Last Quarter

December 13


+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
Lyra
Cygnus
Hercules
Corona Borealis
Bootes
Coma Berenices
sus
Delphinus
Sagitta
Serpens Caput
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Aquarius
Scutum
Virgo
Libra
Capricornus
Corvus
Scorpius
Hydra
Piscis Austrinus
Sagittarius
Microscopium
CrA.
Lupus
Cen.
P
C
U
Z
Y
B
A
M
N
26
25
24
23
22
21
18
17
16
15
14
23h
22h
21h
20h
19h
18h
17h
16h
15h
14h
13h
12h

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.

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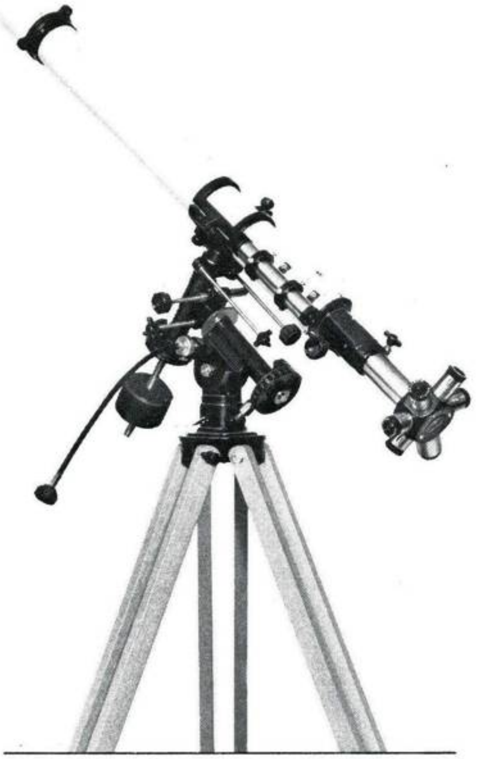

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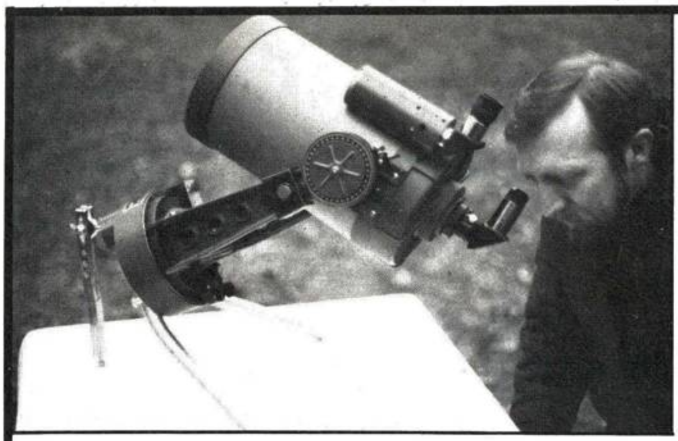

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STAR DOME

DECEMBER

by

James Mullaney and Henry J. Phillips

December is a month of transition. The old year is about to end and give way to the new, and we move from autumn to winter, with all the resultant climatic changes. So it is only natural that the December sky is also in a period of transition, as the comparatively dull skies of autumn are gradually replaced by the bright, crowded winter stars.

By about 10:30 p.m., with the rising of Sirius, the Great Circle of first magnitude stars that marks the winter sky is completely above the horizon. The constellations in which these bright stars are located are prominent and interesting, so it must be a rare stargazer who can resist the impulse to "jump the gun" and begin his study of the winter stars two months early. (The Great Circle will not cross the meridian in the early evening until February.)

Meanwhile, the last of the autumn constellations, currently high in the sky, deserve at least some of our attention. All contain items of interest to the observer, and only the overpowering competition to the east makes them seem insignificant.

South of Andromeda are two small constellations with three conspicuous stars apiece: Triangulum the triangle and Aries the ram. At first, we might expect Triangulum to be one of the inventions of the 18th century French astronomer LaCaille, who placed in the sky such groups as Antlia (the pump), Pyxis (the compass), Horologium (the clock), and Telescopium and Microscopium (which do not need translations). Instead, we discover that Triangulum has been around at least since the Greek era; it was one of the constellations enumerated in the **Phainomena** of Aratus — the first extant Greek star catalog. The Greeks, however, called it Deltoton, from their capital letter Delta (δ).

It is frequently pointed out that Triangulum is one of the few constellations whose stars resemble the object it is supposed to represent. A little thought will reveal that, unless they are arranged in a straight line, any three stars will form a triangle — so we shouldn't feel too amazed at Triangulum's startling likeness.

Among this tiny constellation's points of interest are the alternative titles for its star Alpha: Caput Trianguli and Rasalmothallah — rather long names for a fourth magnitude star in a small star group! In addition, the first asteroid, Ceres, was discovered here on the first evening of the 19th century by Italian astronomer Piazzi. Finally, M-33 — a spiral galaxy and member of the Local Group that some observers can detect without optical aid — is located in Triangulum, near the Pisces border.

A few degrees below the triangle is a delicate curve of three stars of second, third and fourth magnitudes. These stars are the brightest members of Aries the ram. All three stars have lovely names. Alpha, the brightest, is called Hamal, which was the Arabian name for the entire constellation; the word means "sheep". Beta's name is Sheratan, from the Arabian word meaning "sign" and referring to an important function that this star served in the past. For about one century B.C., Beta marked the approximate site of the vernal equinox — the point on the ecliptic at which, upon the sun's reaching it, spring begins. Finally, Gamma is named Mesarthim; the derivation of this word is uncertain. Gamma was one of the first double stars to be discovered (by Robert Hooke in 1664).

The vernal equinox was located within the present borders of Aries from 1730 B.C. to 420 A.D. Because the year traditionally began with the first day of spring during that time, Aries became known as the first of the zodiac constellations — a distinction it still retains, despite the fact that the vernal equinox has since traveled more than 3/4 of the way through the adjoining constellation Pisces. In fact, the vernal equinox is still sometimes called the "First Point of Aries" — a title that more properly belongs to the pseudoscience of astrology than to astronomy.

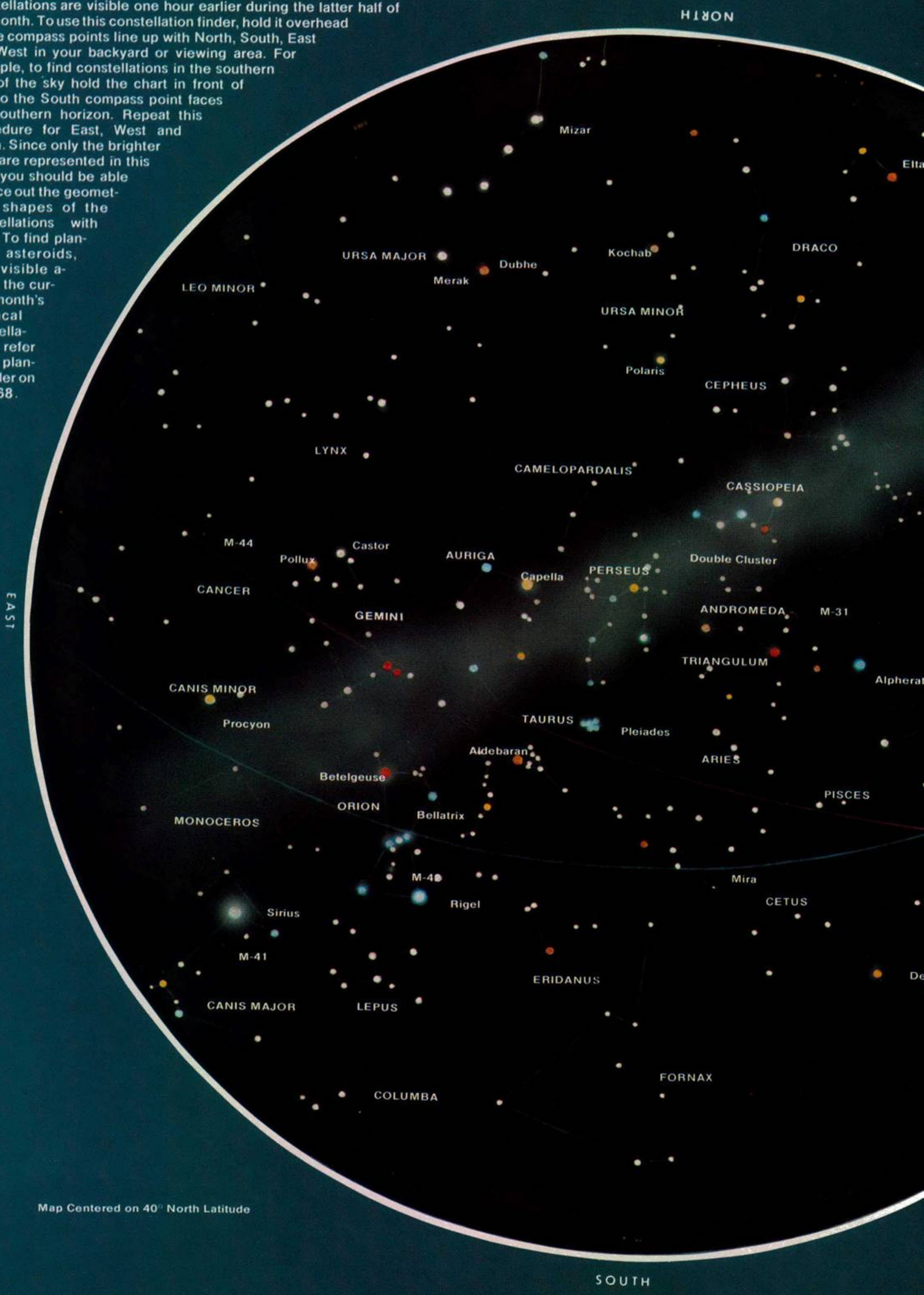
The remainder of Aries stretches toward the east. The small triangle consisting of 35, 39 and 41 Arietis was once the separate constellation Musca Borealis, the northern fly — depicted as hovering over the ram's rump. This group has since been absorbed into Aries, and the only insect in the sky is the original Musca, located south of Crux the southern cross.

East of Aries, situated in Taurus, are the Pleiades — the best known open cluster in the sky. A comparatively young cluster, the Pleiades are believed to be only about 20 million years old; some of these stars are still shrouded in the nebulosity from which they emerged. It appears as delicate wisps of gas in long exposure photographs.

The Pleiades make up M-45, the largest, brightest and nearest of the Messier objects. This is not to say that they were discovered by Messier; the Pleiades have been among the most familiar star groups since earliest time. They, too, once marked the position of the vernal equinox, and their importance in the ancient world was such that they were usually considered a constellation in themselves. It was only late in the Greek era that they became associated with Taurus.

More stories, legends and bits of folklore exist about the Pleiades than any other star group, with the possible exception of the Big Dipper — despite the stars' concentration in a small area and the faintness of its members. Almost every old reference mentions the "Seven Stars", but only six can be clearly delineated with the naked eye by most observers. Does this mean that one of the Pleiades has faded within historical time? Credence is lent this theory by the rapid rotation of some of the stars in the cluster; perhaps if one of them lost enough material, it could have gradually dimmed over the centuries. On the other hand, the number seven was a "perfect" or "magic" number to more

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 68.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GEMINI
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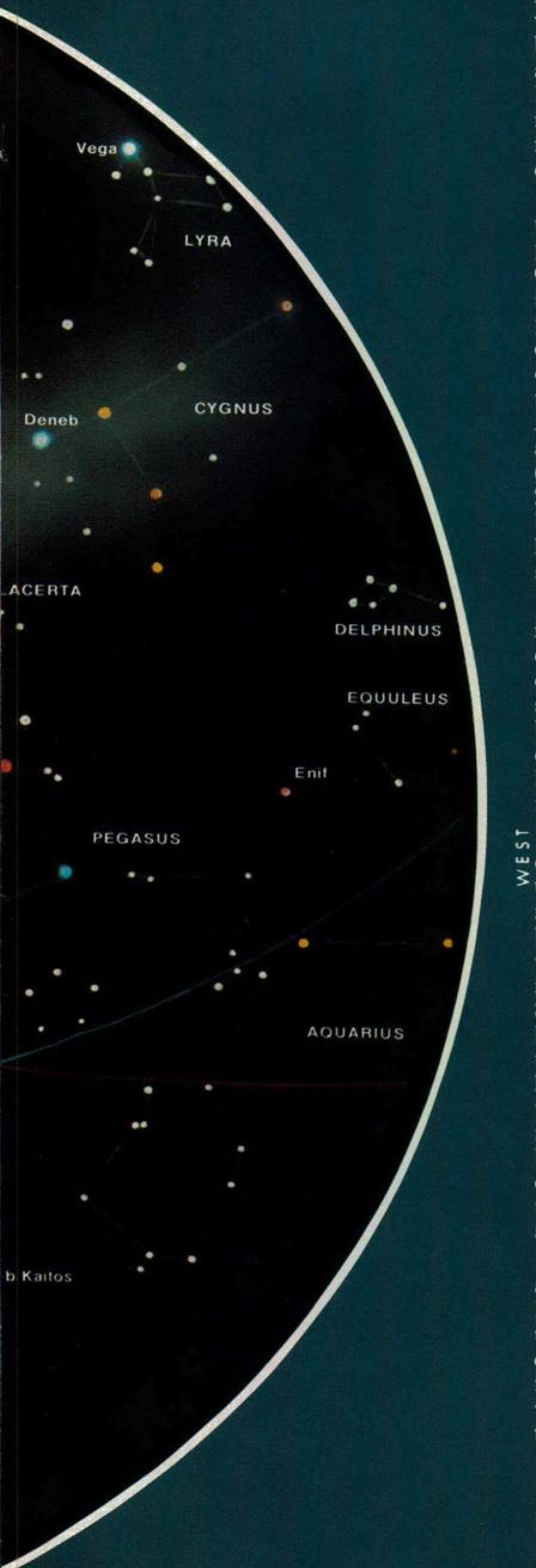
M-42
Mira
Rigel
CETUS
Sirius
M-41
ERIDANUS
De
CANIS MAJOR
LEPUS
FORNAX
COLUMBA
SOUTH

Map Centered on 40° North Latitude



Map by Adolf Schaller

than a few ancient cultures, and priests or other learned men may have assumed that any group as important as the Pleiades would contain seven stars as a matter of course.

Whtaver the explanation, the Greeks invented the tale of the Lost Pleiad, who averted her eyes and dimmed her brightness when Troy fell. We might also note, however, that one of the Pleiades — Alcyone, or Eta Tauri — is markedly brighter than its companions. Are we to interpret this as her exultation over Troy's destruction?

Another Greek story claims that the Pleiades were seven nymphs who, pursued by the boorish, amorous Orion, were changed into doves by a sympathetic god observing their plight. The transformation had little effect on Orion's desires, though, because we can still see him following the Pleiades across the winter sky. Another version states that the Pleiades are seven pigeons that carried ambrosia (the food of the gods) to the infant Zeus. One of them, upon being crushed by the "clashing rocks" of Greek legend, became a dimmer star than its sisters.

Alcyone's comparative brightness is the foundation of another popular conceit — that of the "hen with chicks", by which title these stars are still known in parts of England. Hebrew writers called the cluster the coop; in Russia, they form a sitting hen, and in Poland, a golden hen with five (not six!) baby chicks.

The Iroquois Indians tell an exquisite story about the Pleiades, which they called the Dancing Stars. One night seven brothers were awakened by a distant singing voice. The song was so lovely and so compelling that it irresistibly led them to dance. Soon the voice receded, but the dancing brothers followed it all the way into the sky. One of them looked back and, losing his balance, fell to Earth and was killed. His spirit, however, still moved by the song, caused the body to be turned into a pine tree — tallest of the trees, and still reaching toward the incredible song it can never attain.

Here, again, we have a legend that attempts to account for a "missing" Pleiad. Until further old records come to light, there is no definite proof that one of the stars had faded; but legends from widely separated areas of the world seem to indicate that this is the case.

North of the Pleiades, set in a brilliant portion of the Milky Way, is the constellation Perseus, whose mythology we discussed in last month's Star Dome. The Greek story related there has had wide influence, and Perseus has had few other identifications in its history. To Arabians, it was Hamil Ra's al Ghul (the bearer of the demon's head) — a name derived from the eclipsing binary star Algol the demon.

Although it contains no first magnitude stars, Perseus is a rich, bright constellation. Its most brilliant star, Alpha, is named Mirfak or Algenib. Depending on which name you prefer, this star represents either the elbow or the side of the hero.

Close-Up

Perseus Region

"Here again we enter upon one of the most splendid portions of the galaxy. Night after night the telescope might be employed in sweeping over its magnificent crowds of stars, among which many beautiful pairs, with the aspect of connection, would be found." Thus does Webb introduce us to the glittering wonderland of Perseus, dominating the zenith on cold December evenings.

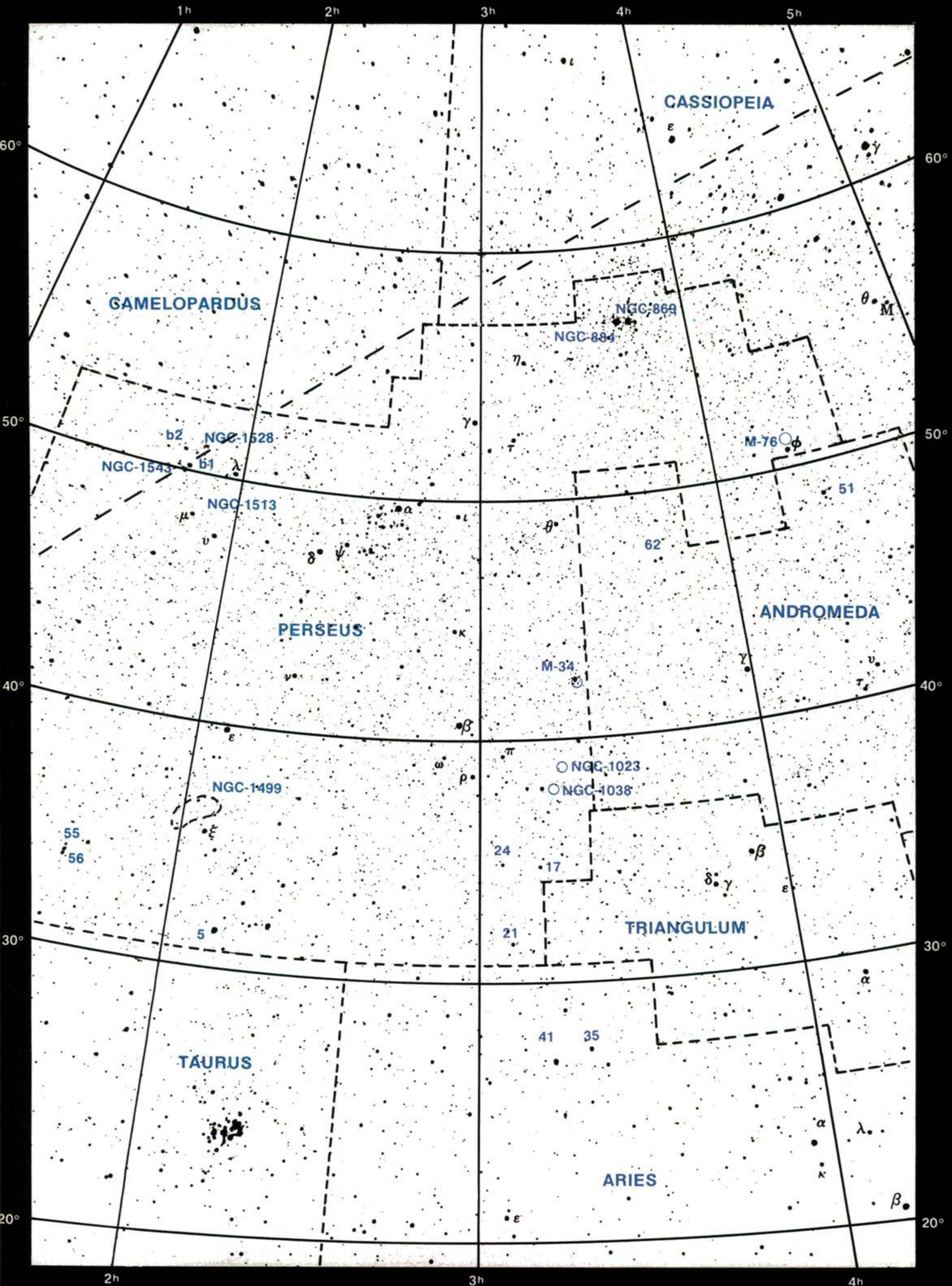
This group is set against a brilliant part of the winter Milky Way. As a result, many of its brighter stars are surrounded by hosts of faint companions, forming apparent clusters virtually everywhere that we point the telescope. Few of these will be found on existing star charts, but they are truly striking. As an example, binoculars and wide field instruments will show a bright splash of stars near Alpha (α) Persei (Mirfak).

Barns called Perseus " a vast stellar revelation", spoke of the "especially inspiring vicinity of Chi Persei", and told of "princely Mirfak throned in the midst of a truly royal council of stars". To see for yourself what these observers of the past are "raving" about, charge up your telescope with a low power, wide field eyepiece the next clear moonless night, and enjoy a session of leisurely sweeping amid the Perseus starclouds.

Algol

Turning our attention from Perseus' spectacular star fields to some of its highlights, we begin with what is perhaps the most popular and conspicuous of the regular variable stars. This is Beta (β) Persei, better known as Algol. Its periodic dimmings were known to the Arabs and others of antiquity, who called this ominous object the "demon star".

Algol is actually not an intrinsic, or "real", variable star at all. It is, rather, an eclipsing binary system in which a "dark" star of spectral class G passes in front of a bright B type sun, partially blocking its radiance. The orbital plane of the pair happens to lie nearly in our line of sight; if it


1h
2h
3h
4h
5h
60°
50°
40°
30°
20°
CASSIOPEIA
CAMELOPARDUS
NGC-869
NGC-884
b2
NGC-1528
NGC-1543
b1
NGC-1513
M-76
51
62
PERSEUS
ANDROMEDA
M-34
NGC-1023
NGC-1038
NGC-1499
55
56
24
17
TRIANGULUM
5
21
41
35
TAURUS
ARIES
2h
3h
4h

Photograph by Robert Provin and Brad Wallis/Map by Richard Berry didn't, the stars would circle each other without eclipsing. Thus, from some other vantage point in space, Algol would not be recognized as a variable star!

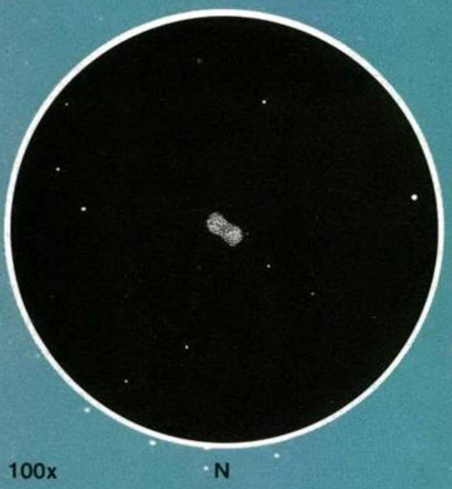
Most of the time the combined light of this system shines at a steady magnitude 2.1. Once every 2 days 21 hours, however, Algol drops more than a magnitude to 3.3 in just a few hours' time. Minimum light lasts only about 20 minutes, followed by an equally rapid recovery. A good reference star to use in checking Algol's brightness is 1.9 magnitude Mirfak.

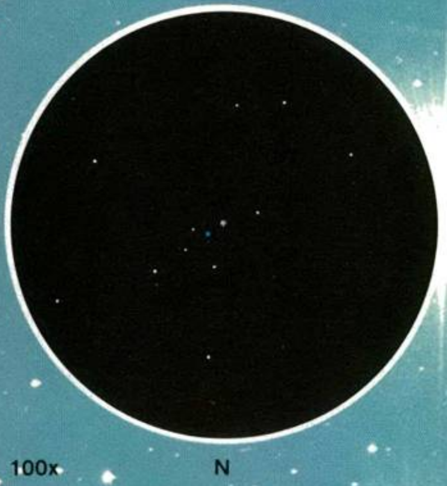
It's fun to see if you can catch the demon star winking at you across space from its distance of more than 100 light-years. Should you see it changing light, gaze at it in awe; before our eyes, without any optical aid, we are witnessing the mutual revolution of one sun about another.

At least one and possibly several other unseen companions to Algol are suspected, resulting in "an enormously complex system" in the words of the noted double star observer Aitken. Telescopically, there are several faint visual attendants — the brightest being a 10th magnitude star about 80 seconds of arc distant.

Eta (η) Persei

Typical of the many double and multiple stars in Perseus having a bright primary and faint companions is the star Eta. A line from Alpha to Gamma (γ) Persei points directly toward it, easily visible to the unaided eye.


M-76


Eta Persei

M-76, known as the Barbell nebula, is a member of the planetary nebulae class. At magnitude 12, it is the dimmest of all Messier objects; only large aperture instruments show it to best advantage. The drawing shows M-76 as seen through a 10 inch reflector; the field of view is 30 minutes of arc. Eta Persei is a magnificent color contrasting double star. The brighter component is a deep yellow or gold color, while the fainter star is a rich blue. Several dimmer field stars give this object the appearance of a small open cluster of stars. A six inch reflector was used for this drawing; the field of view is 30 minutes of arc. Drawings by James Mullaney.

Here we find 3.9 and 8.6 magnitude stars a roomy 28 seconds apart, easy to see in a three inch refractor or four inch reflector at 45 power. A distinct color contrast is evident despite the difference in brightness; this becomes more striking with increasing aperture. While some observers have listed the primary as white in hue, most see it as intense yellow or even orange. All agree in calling the companion deep blue, for its rich color is unmistakable in six inch and larger instruments.

Webb mentioned that there are at least five faint companions to Eta, some of which are shown in our drawing. These may be just part of the background glitter from the Milky Way that we have already noticed, but the 8.6 blue star is drifting with the primary through space as a pair of common proper motion. Eta itself is a spectral class K sun (agreeing well with the visual color impression), and is about 540 light-years from us.

M-76

One of the most elusive Messier objects lurks near the Perseus-Andromeda border, just a degree north of fourth magnitude Phi (ϕ) Persei. This is the dim planetary nebula M-76, considered by some authorities the faintest entry in Messier's list.

Most finders fail to show it, and it is best found by sweeping its position with a wide field eyepiece in the telescope. A four inch aperture at 45 power reveals a faint, elongated glow on a dark night if you use averted vision, and a six inch at 50 to 100 power makes its form definite. Larger instruments give the kind of view shown in our drawing.

M-76 is a 12th magnitude cloud measuring about 160 by 90 seconds in size, somewhat pinched in the middle and brighter at either end. Many observers have likened it to a small version of the well-known Dumbbell nebula (M-27) in Vulpecula, and it is therefore sometimes referred to as the Little Dumbbell. We prefer to call it the Barbell nebula!

Looking much like a double nebula, M-76 carries a dual New General Catalog designation (NGC-650 - 651), and was given separate numbers by Sir William Herschel. It is classified among planetaries as "irregular" and has a very faint central star listed at 16th magnitude. Does it look double to you?

Webb called this object a "Pearly white nebula, double — curious miniature of M-27 . . . preceding (lobe) a little the brighter." Herschel included it in his class I (bright nebulae) rather than class IV (planetary nebulae), and

Selected Objects — Perseus Region

Object	Type	Mag.	Size/Sep.	R.A. (1950)	Dec.
PERSEUS					
*M-76	PN	12	157"x87"	1^h39^m	$+51^\circ 19'$
*NGC-869	OC	4.4	36'	2^h17^m	$+56^\circ 54'$
*NGC-884	OC	4.7	36'	2^h19^m	$+56^\circ 53'$
NGC-1023	El	10	4'x1'	2^h37^m	$+38^\circ 52'$
*M-34	OC	5.5	30'	2^h39^m	$+42^\circ 34'$
*η(Eta)	★2	3.9,8.6	28"	2^h47^m	$+55^\circ 41'$
*β(Beta)	V:2.88^d	2.1-3.3	—	3^h05^m	$+40^\circ 46'$
NGC-1245	OC	6.9	30'	3^h11^m	$+47^\circ 03'$
ζ(Zeta)	★2	2.9,9.4	13"	3^h51^m	$+31^\circ 44'$
ε(Epsilon)	★2	3.0,8.1	9"	3^h55^m	$+39^\circ 52'$
*NGC-1499	DN	—	145'x40'	4^h00^m	$+36^\circ 17'$
NGC-1528	OC	6.2	25'	4^h11^m	$+51^\circ 07'$

*Detailed in Close-Up

★2 = Double Star
OC = Open Cluster
PN = Planetary Nebula
DN = Diffuse Nebula

El = Elliptical Galaxy
V:#^{d} = Variable Star, period (days)
Mag. = Magnitude
Sep. = Separation

Lord Rosse thought it spiral in form. Even Barns was fooled as his description of M-76 shows: "Double spiral nebula, joined, with ring."

This cosmic impersonator lies at least 8,000 light-years from us, buried in the endless strata of stars of our Milky Way galaxy.

NGC-1499

If you find M-76, next try an even more elusive object. This is the large but faint diffuse nebula, NGC-1499, better known as the California nebula because of its unique shape. Often pictured in observatory photos, it's apparently seldom looked at by astronomy enthusiasts.

This ghostly smear of luminescence measures 145 by 40 minutes (or several degrees) of arc in extent, and is so spread out that no definite magnitude can be assigned to it. You can find it centered one degree north of fourth magnitude Xi (ξ) Persei. Slow and careful sweeping with wide field instruments that include at least a degree of the sky will reveal it on a dark night. Scanning back and forth across it is the only way to see its entire outline with normal telescopic fields of view. A six inch reflector at about 30 power will show it faintly glowing against the sky background.

M-34

After straining your eyes and patience trying to glimpse the California nebula, treat them to M-34, one of Perseus' splashy open clusters. Situated a little less than halfway along a line from Algol to Gamma Andromedae, this bright grouping can be seen with the unaided eye on a good night, and is a fine sight in binoculars and finders.

M-34 is a rather loose concentration of some 80 stars in an area the size of the full moon (30 minutes of arc). Its members have a combined or integrated magnitude of 5.5, accounting for its visibility to the eye. Most of the stars are blue-white in color and arranged in pairs radiating outward from a boxlike center.

Webb called this cluster a "very grand low-power field, one of the finest objects of its class". As usual, Barns outdoes everyone with his excited description: "A celestial aegis hung aloft in splendor!"

M-34 is truly stunning in three to six inch instruments at low power, but as telescope size increases and field of view decreases, its appeal fades rapidly. In a 13 inch refractor, for example, at 150 power and 1/3 degree apparent field of view, this object is disappointing. As we have seen before, some celestial showpieces look better in small backyard telescopes than in the largest observatory instruments!

NGC-869 and NGC-884

Saving the best for last, we now examine one of the grandest telescopic sights to be found anywhere in the heavens. This is NGC-896-884, the famed Double Cluster of Perseus.

Easily seen by the unaided eye on a dark night as a double concentration in the winter Milky Way, this duo can be found by following the line of stars [Delta (δ), Alpha, Gamma and Eta Persei] northwest toward Cassiopeia. It also forms a triangle with the stars Delta and Epsilon (ε) Cassiopeiae.

NGC-869 has an integrated magnitude of 4.4, and NGC-884 is 4.7. Both clusters have apparent diameters ranging from 30 to as large as 50 minutes of arc, depending on which authority you consult. Their centers lie 40 to 50 minutes apart, so that they actually overlap. Star counts give 350 to 300 members, respectively, agreeing with the visual impression that 869 is richer than 884.

Although visible to the eye and striking even in binoculars, Messier strangely failed to include the Double Cluster in his famous listing. Some say that it was too well-known and obvious to be mistaken for a comet, and therefore was not logged. If this is the case, what about the Beehive (M-44) and the Pleiades (M-45) clusters, which *were* included?

As it was, it fell to the thorough eye of Herschel to catalog the Double Cluster during his great sweeps of the heavens. They are numbers 33 and 34 in his class VI (very compressed and rich clusters of stars). It was largely the work of William Herschel and his son John that formed the basis of the NGC listing still in use today.

Even a 2.4 inch refractor at 30 power will give a thrilling view of this object, easily including both clusters. A six or eight inch reflector at 50 power places them at opposite sides of the eyepiece field in a spectacle that is difficult to describe in words. As a rule, larger apertures can only fit one cluster at a time fully in the view.

What do observers have to say about the Double Cluster? The NGC description is "Remarkable!" Pickering included them in his famous list of the 60 finest objects in the sky, which covered both northern and southern hemispheres. However, he commented that "neither taken separately is the equal of M-41 or M-35." Some observers may disagree with this assessment, but it should be realized that, from Pickering's observing station in Jamaica, the Double Cluster was much lower in the sky than it is for us.

Olcott said: "A wonderful object. It should be observed with a low power. One of the finest clusters for a small telescope. The field is simply sown with scintillating stars and the contrasting colors are very beautiful." Barns added: "Two splendid naked eye clusters . . . overlapping so as to appear physically connected . . . stars blue-white and intense . . . vivid ruby variable in 884."

Yet another impression was given by Muirden: "A low power reveals two brilliant open clusters, each larger than the moon, set side by side against a background granular with faint stars. This is a superb object, one to which the observer returns again and again; one never tires of surveying this dazzling array of suns, and the only pity is that few telescopes can include both clusters fully in the same field of view."

Like many other observers, Smyth ranked the Double Cluster as "affording together one of the most brilliant telescopic objects in the heavens", and mentioned a ruby and a garnet star in 884, as seen in his six inch refractor. Webb's description also mentioned red stars: "Two gorgeous clusters . . . . With 64 (power) these superb masses are visible together, as well as a bright part north. 5.5 inch (refractor) showed a red star between them . . . 9.3 inch (reflector) shows five red stars in all."

Other observers mention eight or nine reddish stars, mostly associated with 884. These M-type supergiants, sprinkled amid the many blue-white hot stars of types A and B, provide a display of celestial color that has to thrill and excite any star lover. Even a three inch telescope will show these contrasting hues, using averted vision and fully dark adapted eyes.

Have these commentaries missed anything of importance concerning the visual appearance of the Double Cluster? Decidedly yes! Look at the arrangement of the fainter stars as they concentrate toward the center of each cluster with brighter ones surrounding them. It's like looking into a tunnel of stars — a very definite and striking depth effect!

The vicinity around these clusters is also of interest. Note especially the wide cluster of stars designated NGC-957, following just over a degree to the east. Using his 10 inch reflector, Barns said of this area: "Field shot with diamond-dust!"

The distance of the Double Cluster itself is more than 4,000 light-years, or nearly 25 quadrillion miles from us. As we gaze into the colorful cores of these glittering stellar communes, the thought that there must be someone "out there" comes forcibly to mind. So strong is this feeling that we may find the simple, haunting words of Enrico Fermi on our lips: "Where are they?"

Celestron 5 Photographs: Left, the Double Cluster in Perseus; Right, Galaxy M 33

Celestron 8 Photographs: Left, the Trifid Nebula; Right, the Omega Nebula

Photographs by Leo C. Henzl, Jr.

Celestron 14 Photographs: Left, the Dumbbell Nebula; Right, the Ring Nebula

Ever wonder why most telescope manufacturers only show you pictures of telescopes in their ads?

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